UNIVERSITY OF CALIFORNIA PUBLICATIONS
IN
AGRICULTURAL SCIENCES
Vol. 3, No. 8, pp. 135-242, plates 13-24 July 12, 1918

THE CHEMICAL COMPOSITION OF THE PLANT AS FURTHER PROOF OF THE CLOSE RELATION BETWEEN ANTAGONISM AND CELL PERMEABILITY

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CONTENTS

PAGE
Introduction 135
Object of the investigation 137
Review of previous investigations 137
Methods 140
Experimental data 144
External appearances of the plants 154
General review of experimental results 155
Results with salts of the heavy metals 156
Possible effects of variations in the concentrations of the solutions on the plants 160
Consideration of a possible Calcium-Magnesium ratio 160
Permeability and antagonism 162
Summary 164

Introduction

A solution of a single salt at certain concentrations is toxic to plants grown in it. The addition of a second salt usually permits of growth superior to that in a solution of a single salt alone even though the added salt is toxic when used by itself. A third salt added may permit of a still further increase over the growth in the two salt solution. Other salts added will increase or decrease growth, depending upon the salt used. Qualitative relationships only have been considered. When we adjust the quantitative relationships of the various salts present, having at the same time due regard for their qualitative

nature, we get as a result a solution in which the plant grows and functions normally. Such a solution has been termed by Loeb, "physiologically balanced."

It is evident that if growth is better in a two salt solution the toxic effects of the solution due to a single salt must be lessened by the presence of the second salt. We may refer to either as the second salt since either may be toxic alone. On the addition of a third salt the increase in growth over that obtained in the two salt solution points to a still further lessening of the toxic properties of the various salts present taken singly. This action of one or more salts in limiting or preventing entirely the toxic effects of one or more other salts, is termed antagonism. Sea water may be taken as an example of a physiologically balanced solution or a solution in which the mutual antagonism between the constituents of the solution is such as to allow of normal growth of numerous organisms.

The fact of the existence of antagonism has been proven by a number of investigators working in plant and animal physiology, but the mechanism of antagonistic action is by no means clear. Since salts are very largely ionized in the nutrient solutions usually employed, it is probable that antagonism has to do with ions. Further, antagonism will probably take place between the ions present in, or between, the ionic constituents of the solution, and the living membranes in contact with the solution. Loeb[1] first advanced the theory that one ion may prevent the entrance of another ion into living cells and that in this property lies the reason for antagonistic action. On the basis of this hypothesis, penetration precedes the manifestations of toxic effects and where penetration does not occur, due to antagonistic action, there are no toxic effects evident. Used in this way, the term penetration means simply the entrance of ions in greater number than would normally occur were the plant cells in their natural environment. Experimental evidence as to the correctness of this hypothesis has been furnished by Loeb[2] in a very interesting series of experiments. Osterhout[3] has applied the electrical conductivity method to the measurement of the penetration of ions into plant tissue, while recently Brooks has confirmed Osterhout's results (1) by determining: the diffusion of ions through tissue,[4] (2) by exosmosis,[5] and (3) by the change in the curvature of tissue.[6]

[1] Amer. Jour. Physiol., vol. 6 (1902), p. 411.
[2] Science, n.s., vol. 36, no. 932, p. 637.
[3] *Ibid.*, vol. 35, no. 890, p. 112.
[4] Proc. Nat. Acad., Sci., vol. 2 (1916), p. 569.
[5] Amer. Jour. Bot., vol. 3 (1916), p. 483.

It is evident that these methods are limited in their application and give no idea of the quantitative relationships existing between the ions actually entering the cells. They do show, however, that the permeability of the plant tissue may be greatly altered by salt action and that solutions which permit of normal growth also preserve normal permeability as regards the ions present in the solution.

Object of the Investigation

In a preliminary paper[7] the results obtained from chemical analyses of plants grown in toxic and antagonistic solutions have been reported. These results were of interest and the general method employed seemed to be worthy of a more extended application in the determination of ions absorbed by plants from solutions, of known composition and concentration. From a consideration of the data in the paper referred to above, it was felt that the results obtained in a more extensive investigation would be of importance: (1) from the standpoint of the effect of various salts upon the permeability of the cell tissue of growing plants; (2) from that of the effects of various salts upon the nutrition of plants as evidenced by growth; (3) from that of a possible correlation of growth with the absorption of ions; and (4) from the standpoint of the quantitative relationships existing between certain ions of the solution and the same ionic relationships in the plant.

The various phases of the problem as outlined above will be considered in the discussion of the experimental results following.

Review of Previous Investigations

It is not intended that the following review of the previous work done in this field of plant physiology be exhaustive. Robertson[8] has reviewed the literature dealing with antagonistic salt action very completely up to a recent date. Brenchley[9] and Lipman and Gericke[10] have referred to all the important work done with regard to the effects of the salts of the heavy metals upon plants. The present review therefore touches only the work bearing directly upon the

[6] *Ibid.*, p. 562.

[7] Contribution to the causes of antagonism between ions. (Univ. Calif., Master's thesis, 1915.)

[8] Ergeb. Physiol. Jahrb., vol. 10 (1910), p. 216.

[9] Inorganic plant poisons and stimulants. New York, Putnam, 1915 (Cambridge agricultural monographs).

[10] Univ. Calif. Publ. Agr. Sci., vol. 1 (1917), p. 495.

present problem or work so recent as not to be included in the papers cited above.

A large share of the contribution to the experimental evidence in regard to antagonism between salts as regards plants we owe to Osterhout. In a series of papers he has shown that any salt may be toxic to plants when used alone in solution at certain concentrations and further that the addition of a second salt may, in proper concentration, modify or eliminate entirely the toxic effect of the first salt. He has shown further that acids, alkalies, and various organic compounds may likewise be toxic to plants and that their toxic effects may be modified by the presence of a variety of compounds, depending upon the toxic substance employed. By measuring the resistance of cylinders of Laminaria in solutions of one salt and in solutions containing two or more salts, he has brought forward much evidence as to the penetration of ions into plant cells. While this method has yielded very valuable results both as to the rate of entrance of ions and also the total number of ions penetrating, it does not yield results which give us a knowledge of the relative amounts of the various ions which penetrate the tissue when the qualitative as well as the quantitative relationships of the nutrient solution are varied. Osterhout has shown, however, that penetration is more rapid, and the degree of permeability is greatly increased, in unbalanced solutions and further that as the permeability of the plant tissue more nearly approaches normal the growth of the plant is also more nearly normal.

Szues[11] has used *Cucurbita pepo* as an indicator by immersing the young seedlings in various solutions for varying periods of time and counting those still able to show geotropic movement when placed in a horizontal position in a moist chamber. He found a marked antagonism between copper sulphate and aluminum chloride and concludes from his experiments that antagonism consists in the mutual hindrance of similarly charged ions in entering the cell. He states further that the rate of absorption of equally charged ions is of great importance. His chemical methods are open to question, for in the experiments reported the test for copper used was that of boiling the roots and testing the resulting solution for copper with hydrogen sulphide.

By analyzing the solution in which pea seedlings had grown, Pantelli[12] has determined ion absorption. The growing period was short.

[11] Jahrb. Wiss. Bot. (Pringheim), vol. 52, no. 1 (1912), p. 85.

[12] *Ibid.*, p. 211.

He found a rapid absorption of zinc, manganese, iron, and aluminum, but the total amounts taken up were small. He gives other evidence of the selective absorption of various other ions from solutions, but these results are of not direct application here. It is of interest to note, however, that he found a direct relation between time and ion absorption. His most important conclusion, which bears directly upon the problem in hand, is that strong narcosis was associated with the penetration of ions in large numbers.

Schreiner and Skinner,[13] using a similar method, have determined the amounts of phosphoric acid, nitrates, and potassium remaining in a solution in which plants had been grown. Various ratios of these three ions were employed, the total concentration being 80 parts per million. They found widely varying amounts of these three ions removed from the solution, and further there seemed to be a possible difference of 20 to 30 per cent in the removal of any one without an apparent effect upon the growth of the plants. Under the conditions reported by them increased growth was correlated with increased absorption.

By means of conductivity measurements of solutions in which pea seedlings were growing, True and Bartlett[14, 15, 16] have determined the rate of absorption and of excretion of electrolytes. Their work was done with one, two and three salt solutions. In general they found a greater absorption when a mixture of salts was present than when single salts were used. Further, the absorption relationships of salts with a common kation seem to be similar. For example, from solutions of low concentrations, potassium chloride, potassium sulphate, and potassium nitrate are not removed, but on the other hand there is an excretion of electrolytes by the plant. In direct contrast, calcium nitrate and calcium sulphate are removed from their solutions in every concentration employed and no excretion of electrolytes from the plants could be detected. It seems probable that the low concentration employed by them acted as a limiting factor in some cases.

In a recent paper Breazeale[17] has shown that the presence of sodium carbonate, and sodium sulphate, when used in concentrations of 1000 parts per million in nutrient solutions, decreased the absorp-

[13] Bot. Gaz., vol. 50 (1910), p. 1.

[14] Amer. Jour. Bot., vol. 2 (1915), p. 255.

[15] *Ibid.*, p. 311.

[16] *Ibid.*, vol. 3 (1915), p. 47.

[17] Jour. Agr. Research, vol. 7 (1916), p. 407.

tion of potassium and phosphoric acid as much as 70 per cent below that of the control cultures.

The work of Gile[18] is of interest in this connection. From ash analyses obtained in investigating the cause of chlorosis in pineapples, he found a direct relationship between the absorption of lime and that of iron; that is, when the absorption of lime was high but little iron was taken up. In soil studies Gile and Ageton[19] found no direct relation between the lime content of plants and varying amounts of lime and magnesia in the soil.

A few investigations have been made on the absorption of specific elements from solution, but these need only be mentioned in the present connection. Maquenne[20] found that mercuric chloride causes marked increase in permeability of the protoplasm, although it is not necessarily absorbed itself in any considerable quantities. Marsh[21] correlates the amount of barium chloride present in the soil with that found in the plant. Colin and De Rufz[22] always found absorbed barium localized in the roots.

A large number of analyses of plants grown under various conditions have been reported, but the environmental factors have varied so greatly as to render the results obtained of little value in the present study.

From this review it is evident that no quantitative study of the elements actually absorbed from the nutrient solutions, balanced and unbalanced, has been made with the idea in mind of a correlation between the absorption of the various ions with their antagonistic or toxic effects in solution cultures.

Methods

Barley was used as the plant indicator. The seeds were obtained from the University Farm at Davis and were of a pure strain of the Beldi variety. The method of sprouting the seeds, while simple, has not been noted elsewhere and has given such excellent results, both to the writer and to others, that it seems worthy of mention here in detail. A piece of oilcloth about 12 x 18 inches was covered with several thicknesses of paper toweling and the whole thoroughly wetted.

[18] Porto Rico Exp. Sta. Bull., 11 (1911).

[19] *Ibid.*, Bull. 16 (1914).

[20] C.-R. Acad. Sci. (Paris), vol. 123 (1896), p. 898.

[21] Bot. Gaz., vol. 54 (1912), p. 250.

[22] C.-R. Acad. Sci. (Paris), vol. 150 (1910), p. 1074.

Selected seeds were distributed over the toweling so that about two hundred were placed on an area of the size indicated above. Another layer, made up of several sheets of toweling, was then laid on the seeds and the whole thoroughly soaked with water. The water was allowed to evaporate gradually until the paper was but slightly moist to the touch and the water relation then maintained constant until the seedlings were transferred to the solutions. If the paper is kept too moist the growth of molds is often very abundant, but with a low moisture content no trouble was experienced from this source. By the time the roots were a quarter of an inch long, the upper layer of paper was supported two or three inches above the seedlings. This procedure permits of a straight growth of the shoots, which is of considerable importance in placing the seedlings in the corks. The seedlings were transferred when the shoots were about an inch and a half in length. The paper in which the roots are grown, tears apart readily without injuring them in any way, the oilcloth not permitting their downward penetration. There is no contact with metal containers at any time, the apparatus required is practically nothing, the time period is short—about six days under greenhouse conditions—and strong seedlings are obtained which can be transferred to any containers without injury.

The containers used were quart jars of the Mason type, each holding approximately 950 c.c. of solution. The inside of each jar, as well as that of the bottles for the stock solutions, was coated with a layer of paraffin so that the solutions were never in contact with the glass. The outside of the jar was covered with black paper to exclude light, the black surface facing the glass. Flat corks, having a diameter of three and a half inches, were used to support the seedlings. Each cork had seven holes, one in the center through which distilled water was added to maintain the volume of the solution as nearly constant as possible, and six equally spaced, one and a quarter inches from the center, for holding the seedlings. After the holes were made the corks were soaked in boiling paraffin.

To introduce the seedlings the corks were turned upside down, supported by the rim of the jar, and the shoots stuck through the holes prepared for them and held in place by a small piece of cotton. On turning the corks over the seedlings were in their proper position without being in the least injured, for there was no necessity for touching the roots at any stage since the plant was always picked up by the seed coat. The method suggested by Tottingham[23] was tried,

but the one outlined above proved very satisfactory and much simpler.

The basic nutrient solution used throughout was Shive's three salt nutrient[24] containing the following salts in the given partial molecular concentrations:

$K H_2 PO_4$	.0180 M.
$Ca (NO_3)_2$	.0052 M.
$MgSO_4$	.0150 M.

The stock solution was made up to twice the strength indicated above and diluted as necessary by the addition of added salt solution, or distilled water, or both.

In the case of the chlorides used, viz., calcium, magnesium and potassium, normal or twice normal solutions were prepared and standardized by titrating against a standard silver nitrate solution. Normal solutions of magnesium and potassium sulphate were standardized by weighing the barium sulphate precipitate. Solutions of copper, zinc, iron, and mercury salts were prepared in concentrations of 1000 parts per million by weighing out the carefully dried salts.

The final volume of solution required for the duplicate jars was approximately two thousand cubic centimenters. Starting with a thousand of the nutrient solution, various volumes of the standard solutions were added so that when the total volume was made up to two liters with distilled water, the concentrations of the various salts would be those reported in the accompanying tables.

The growing period was six weeks. The duplicate cultures were grown in specially constructed mouse-proof cages each holding ninety jars. The tops of the cages were open and the sides made of coarse wire screening. The different parts of the cages were equally well lighted, as shown by the nearly equal growth of the controls in different parts of the cages. When necessary the plants were supported by cords strung across from side to side of the cages.

The solutions were not changed during the growing period, but the volumes were kept as nearly constant as possible by adding distilled water. There are objections to this method, as there are objections to the method of using water cultures at all. The growth was found to be very satisfactory and compares favorably with the growth

[23] Physiol. Researches, no. 4 (1915), p. 174.

[24] Amer. Jour. Bot., vol. 2 (1915), p. 157.

obtained by other investigators in comparable periods of time. A further discussion of this point will be taken up below.

At the expiration of the six weeks growing period the plants were removed from the corks, the roots rinsed thoroughly with distilled water, placed between layers of paper toweling, dried in the oven at 100°–105°C, roots and tops separated, weighed, and placed in envelopes ready for analysis. For analysis the roots from duplicate cultures were combined unless the dry weight was sufficient to allow of separate analysis.

Total ash was determined after direct ignition of the dry material in a muffle at a low red heat until no trace of carbon remained. The ash was then taken up in dilute hydrochloric acid and evaporated to dryness to remove possible contamination with silica. Iron was precipitated as the hydroxide with ammonia and titrated with $\frac{N}{100}$ potassium permanganate after reduction with zinc and sulphuric acid. This determination was made because of the relation Gile has shown to exist between calcium and iron absorption by plants. Calcium was precipitated as oxalate and titrated with $\frac{N}{100}$ potassium permanganate. The double precipitation of the oxalate assured freedom from magnesium contamination. Magnesium was precipitated by ammonium phosphate and weighed as the pyrophosphate. Potassium, where determined, was precipitated and weighed as the chloroplatinate. Copper was determined colorometrically by using the ferrocyanide method. The amount of material available precluded the possibility of a more complete analysis than was made if any degree of accuracy was desired. For example, in Series VII, the weight of the ash varied from 12 to 233 milligrams in the case of the roots and from 32 to 183 milligrams in the case of the tops. While these variations are not extreme, they are fairly representative. The values of these elements actually determined cannot be taken as absolute in every case because of the limited amounts of material available, but the significant differences are so great as to make a small variation in this regard of minor importance.

The strength of all solutions is uniformly expressed in terms of molecular concentrations since this mode of expression has been quite generally used in experimental work reported by different investigators.

Under experimental results twenty-six series are reported. A series, as used in the present work, may be defined as a number of

duplicate cultures containing one salt in varying concentrations in each, or one salt constant and varying concentrations of a second salt. In some instances both salts varied but only in concentration, the same ratios being maintained. These are few. The number of concentrations reported vary from three to fourteen in a series, depending upon the salt used. Before two salts were taken together, the effects of each separately upon the plants were determined. Usually this meant only the establishment of the toxic limits of the salts employed when used in the nutrient solution. Several series of this kind are not reported here, as no analytical work was done upon them.

Calcium and magnesium salts were used to a large extent because of the fact that their kations can be determined with less experimental error than most other nutrient salts where the small amounts of material dealt with here are considered; also it was of interest to determine whether or not there is a lime-magnesia ratio for plants grown under carefully controlled conditions. Copper, zinc, iron, and mercury salts were used because of the fact that their toxic and antagonistic effects have not been previously determined as regards absorption. Potassium chloride was the only monovalent salt used.

A longer growing period than has usually been employed was considered important. McGowan,[25] in conducting experiments in pure solutions of sodium, potassium and calcium chlorides, found growth better in the first two at the end of six days, but far superior in a solution of calcium chloride in twenty-five days. In a qualitative way the same relationships were observed in the present investigation. It seems reasonable to assume that the results obtained in six weeks with plants are more nearly representative of the true effect of various solutions than those obtained in two or three day periods or even in three week periods. But it is not assumed that the results herein reported are the same as those which might be obtained were the plants grown to maturity. It is hoped that more data may be presented shortly on this point.

In the following section, in which the experimental results are given, the time factor and the basic nutrient solutions are constants.

Experimental Data

All analyses are reported as percentages of the dry weights of the plants. To make the results obtained as clear as possible, graphs and photographs have been used throughout as well as the tables giving the actual percentage composition of the plants.

[25] Bot. Gaz., vol. 45 (1908), p. 45.

The relationships of calcium to magnesium salts are reported in the first seven tables. For a review of the more important literature bearing directly upon the relationships of the salts to these two elements reference is made to McCool,[26] who has considered these in some detail, and to a recent critical survey of the lime-magnesia ratio hypothesis by Lipman.[27]

As is evident from table 1, calcium chloride does not become toxic until present in concentration of over .24 M. Up to and including this concentration the growth seems to be but little affected by the increasing concentrations of the salt added. The percentage of calcium in the plants shows no direct increase with increasing concentration of calcium chloride in the solution. The lowest percentage of calcium given occurs in a concentration of .20 M. calcium chloride.

In table 2 there is a close parallelism between the growth of roots and tops. Two low points on the dry weight graph are evident, the first occurring at cultures 4 and 5 and the second from 7 to 11. At these low points we have a high percentage of magnesium in both roots and tops, but of calcium only in the second low point. Calcium is low where growth is good in cultures 2 and 3. But the most interesting feature is the decreased absorption of both elements at culture 6, where there is a distinct increase in dry weight. Iron was not present in sufficient concentration to allow of titration until culture 11 is reached. It may be stated here that the iron determined is limited to that in the seed as a maximum, for it was purposely excluded from the solutions except where its toxic or antagonistic action was under observation. In many instances the titration of this residual iron is of interest.

Table 3 is a record of one of the most interesting and significant series reported. The root growth was so limited in nearly every culture that no attempt was made to segregate roots from tops for separate determinations except where the total dry weight was so greatly increased as in cultures 6 and 11. In the first place we have double maxima of growth, the first in culture 6 and the second in 11. The total dry weight at culture 11 is twice that at 6, but the dry weight in culture 6 amounts to a 35 per cent increase over that in culture 7. A direct inverse relationship is shown between total growth and absorption at these two high points; the maximum growth in culture 11 is accompanied by the lowest absorption of calcium and magnesium. The percentage of magnesium is low in culture 6, but that of calcium

[26] Cornell Univ. Agr. Exp. Sta. Mem. 2 (1913), p. 127.
[27] Plant world, vol. 19 (1916), p. 83.

is higher than in the cultures of slightly higher or lower concentrations. No explanation of the narrow ratio between these two elements at this point can be offered. It is of interest to note the very great increase in the amounts of calcium and magnesium found in the plants grown in concentrations of .20 M. calcium chloride alone. While magnesium chloride is constant throughout the series, the amount of magnesium does not increase proportionately to that of calcium.

A still higher concentration of magnesium chloride was used in the series reported in table 4. The percentage of magnesium found in the roots is very high and would indicate that it was not entirely removed from the roots by washing. In general the percentages of calcium and magnesium found are high, the calcium content increasing as the concentration of calcium chloride present in the culture, but not proportionately. Magnesium is lower at the greater dry weights for the tops, the decrease amounting to 50 per cent in the case of culture 6.

Magnesium sulphate was used alone in the series reported in table 5. The decrease in growth is nearly proportional to the increase in concentration of the added salt. In this series we have a very marked decrease in the percentages of calcium and magnesium present in the roots without any evident effect upon the growth of the plants, especially that of the tops. Here again, however, we have increased absorption of calcium as the percentage of magnesium increases, even though the concentration of the former in the nutrient solution is constant. It is of interest to note that the percentages of both elements in the tops throughout this series are low and vary but little, regardless of the increasing concentration of the nutrient solution.

Very marked antagonism between calcium chloride and magnesium sulphate is shown in table 6. The dry weight of the plants grown in a solution of magnesium sulphate .18 M. concentration was .29 gram, but when .04 M. concentration of calcium chloride was added the average dry weight was 1.20 grams and in a concentration of .18 M. magnesium sulphate and .24 M. calcium chloride the average dry weight was .98 gram. Between these two concentrations of calcium chloride the dry weights recorded are uniformly high. Correlated with the rapid decrease in growth, in concentrations of .24 M. of calcium chloride, is the marked increase in the percentage of both calcium and magnesium found in the plants. The graphs representing the amounts of these elements found crosses the growth graph coincident

with its sharp decline. The low percentage of magnesium is of interest since the concentration of the culture solution was uniformly high with respect to this ion.

It is striking that there is a marked decrease in the growth of roots at the concentration which gave the best growth of tops, and further that the percentage of calcium in the tops and magnesium in the roots parallel this decrease in the growth of the roots. A comparison of the results obtained with magnesium sulphate as against those with magnesium chloride is reserved for later discussion.

In table 7 we have an opportunity to compare indirectly anion effects, or possibly the effects of combinations of the same kation with different anions. From preliminary results it seemed advisable to use .15 M. magnesium sulphate in this series instead of .18 M. as used in the preceding series, so that the concentration of magnesium ion is not equivalent in the two series. A solution containing magnesium sulphate .15 M. plus calcium nitrate .08 M. proved highly toxic, while a solution containing calcium chloride of the same concentration as the nitrate in the above solution supported normal growth. It is possible that the difference is due to the toxic action of the nitrate ion on the plant directly. Tottingham has shown that the total ionization of a nutrient solution was decreased 10 per cent below the theoretical by the addition of calcium nitrate in low concentrations. It is possible that the ionization of some other salt is repressed so that there is an actual lack of some ion necessary for growth. The percentage of calcium found was not high enough in any case to account for the toxic effects shown. Magnesium was found in extremely large amounts, 9.20 per cent in the case of culture 6, the largest percentage recorded in any culture studied. Unfortunately the series in which the toxic effects of calcium nitrate alone were studied was lost, so it cannot be reported here.

Potassium chloride was the only monovalent salt studied, and the results are given in tables 8 and 9. The growth shown in the various concentrations of potassium chloride used was approximately the same as that found when magnesium sulphate was used alone. The increase in the percentage of ash, as far as the tops are concerned in table 8 is very striking. The percentage of calcium found in the tops and of magnesium found in the roots remains practically constant throughout. The amount of potassium absorbed increases as the concentration of potassium chloride in the solution increases and inversely as the growth of the plants. The toxic effects due to the

addition of potassium chloride to the solution are much more evident in the tops than in the roots with respect to the increasing concentrations of potassium chloride.

Using a constant concentration of potassium chloride of .18 M., which is an increase of .02 M. over the highest concentration of that salt reported in table 8, against varying concentrations of magnesium sulphate, the results reported in table 9 were obtained. There is a marked increase in total ash as the concentration of the nutrient solution with respect to magnesium sulphate increases. Parallel with this increase is the higher percentage of potassium. The growth decreases inversely. Antagonism between the two salts is evident where the lower concentrations of magnesium sulphate were used. In cultures 2 and 4 of this series, we have a marked increase in growth over that of culture 3. Absorption is markedly lower at the two high points than at the intermediate concentration, where the solution is evidently more toxic. The least growth obtained in the series was recorded in culture 7, which shows the highest absorption of all the elements determined. In the two higher concentrations of magnesium sulphate used the growth was increased somewhat while the percentage of calcium, magnesium, and potassium in the plants decreased markedly. It seems worthy of note that the amount of iron in the ash was not sufficient to allow of titration at any concentration employed in the series. This series very well illustrates the point which has been brought out a number of times before of the relationship between absorption and growth. Here we have five cultures in the one series of which this relationship is evident. The relations are not absolute in every instance, but there can be no doubt whatever of the tendency toward decreased absorption as growth increases, or that antagonism between ions results in decreased absorption of at least some of the ions present in the nutrient solution.

We turn now to a consideration of the effects of a few of the salts of the heavy metals upon growth and absorption. In table 10 the effects of adding various concentrations of aluminum chloride are shown. Growth is decreased in every concentration of the salt used. The high percentage of magnesium is marked in both roots and tops. On the other hand, the percentage of calcium is increased relatively little. The percentage of iron found was practically constant and in total quantity is in marked contrast to the last series considered in which the amount was so small that it could not be determined.

In a solution of .20 M. calcium chloride, the results with the vary-

ing concentrations of aluminum chloride are shown in table 11. In general the toxic effects of the two salts seem to be *additive,* that is, the growth in this series in which two salts are present together is less than in the preceding series where aluminum chloride was used alone. The decrease is not great from the standpoint of total weight, but proportionately is very considerable, amounting to from 33 per cent to 100 per cent in the various concentrations employed. The percentage of magnesium in the two series is about the same. The amount of calcium absorbed, on the other hand, is increased over 300 per cent and remains constant throughout. The total absorption with respect to calcium and magnesium, at least, is uniformly high. This fact is reflected in the increase in the percentage of ash over that of the control. In the next series all factors are the same except that magnesium chloride was used instead of calcium chloride, there being no difference whatever in partial or total concentration. The antagonism shown between magnesium chloride and aluminum chloride in culture 4 is very marked, and correlated with the increased growth is the marked decrease in the percentage of both magnesium and calcium found in tops and roots. The percentage of magnesium found in the plants is not proportional to the concentration in the solution as was true with calcium chloride. An interesting case of the increased absorption of one element with a decrease in the other is well illustrated in the case of culture 6 of this series. Such a relationship has been noted previously, but is apparently of no direct importance from the standpoint of growth.

Ferric chloride, a second trivalent salt, was used in the nutrient solution in the concentration shown in table 13. In the concentration employed, growth is nearly normal and absorption is very nearly the same as with plants in the control cultures, except in the case of calcium. The decrease in some instances in the percentage of calcium found, as iron increases in the nutrient solution, is notable, and will be referred to later in connection with the action of ferric and zinc sulphates.

The effects of adding .20 M. calcium chloride, together with various concentrations of ferric chloride, are given in table 14. The growth of roots and top parallel each other closely. Marked toxic effects are evident in certain combinations as in cultures 3 and 7. The percentage of calcium found in both roots and tops is high in plants grown in the same cultures. The magnesium present in the tops shows the same relationships as the calcium, although the

amount absorbed varies but little from that of the control. In the roots magnesium is present in large amount when growth is low in culture 2, but in succeeding cultures the percentage found falls off sharply and remains abnormally low without any relation to growth or concentration of the solution. The percentage of iron is high in cultures 6 and 7, in which the weight of the plants was small.

Substituting magnesium chloride in equivalent concentration for the calcium chloride used in the preceding series, the results are of a very different order from those in table 15. The absolute growth of the tops is greater than in series 14. Root growth does not parallel the growth of the tops. The toxicity of the solution is scarcely evident at some concentrations while markedly increased at others. Absorption, with the exception of the magnesium in the roots, is usually low, amounting to about that of the control, but the percentages of calcium and magnesium found bear no apparent relation to the differences in growth. Iron, however, shows the inverse relation already noted in many other series with calcium and magnesium, that is, high percentage present when growth is low, and vice versa. The toxic and antagonistic effects as well may be due in this instance to the ferric ion, but this statement is by no means indisputable.

In several tables following, the effects of copper salts are given. Previously copper salts have been shown to be highly toxic to plants as well as to a wide variety of vegetative forms. That they may also be stimulating has been shown recently by Forbes[28] using solution cultures, and by Lipman and Gericke[29] in soil cultures. The reader is referred to the latter paper for an extensive review of the subject.

The results with copper chloride are reported in table 16. Growth, especially that of the roots, was limited in every concentration reported. In fact, the growth of the roots was so limited that their weights are not given. There is a suggestion of antagonistic action between the nutrient solution and copper chloride in cultures 3 and 5. The percentage of magnesium found is high where growth is low. The same is not true of calcium, the percentage of which is low and decreases as growth decreases to a certain extent. A trace of copper was found in every case and appreciable amounts had penetrated the plant tissue at the two higher concentrations. When ferric chloride is added together with copper chloride marked antagonism is shown. Table 17 will make this effect evident. In this series, as in

[28] Univ. Calif. Publ. Agr. Sci., vol. 1 (1917), p. 395.

[29] *Ibid.*, p. 495.

several following, the concentrations of both salts added increase, that is, both increasing but bearing the same ratio between the two. There is an increase of approximately 100 per cent in the dry weight of culture 2 over cultures 1 and 3. The low absorption of culture 2 as related to 1 and 3 is evident. There is a marked decrease in the percentages of calcium and magnesium found in the plants grown in culture 5, in which the dry weight of the plants was also low. At this second point, however, iron and copper were found in larger amounts than at any other concentration used. As in the previous series the percentage of calcium in the tops does not seem to parallel that in the roots or of magnesium in either roots or tops. A similar relationship was brought out in the previous series in which copper chloride alone was used. No apparent precipitation took place upon the addition of iron in the concentrations given, but a precipitate composed of ferric phosphate was present at the time of harvesting. It is possible that double salts of copper or iron with calcium or magnesium and, for instance, the phosphate ion were formed at the higher concentrations. Their complexes may not be taken up by the plants and hence actual starvation as far as these elements are concerned, may be responsible for the low amounts found in the plants. Such a condition contrasts directly with one in which there is low permeability due to antagonistic effects between the ions in the solution.

In table 18 mercuric chloride was used with copper chloride, since it was desired to determine the effects produced by the addition of two highly toxic salts to the nutrient solution. The results with mercuric chloride alone are given in table 26. They are somewhat irregular, but there can be no doubt of the correlation between the quantitative presence of calcium and magnesium in the tops, of magnesium in the roots, and growth. There is evidence of a distinct antagonistic action between copper and mercuric chlorides both from the standpoint of growth and that of absorption. The root growth was very limited. The percentage of calcium and magnesium in the roots was very high; high enough to account for the decreased growth by itself if we use the results of other series in interpreting this one. Not enough iron was present in any culture to permit of its determination.

Considering the most common salt of copper used in solution cultures and soil work, the results as given in table 19 are especially noteworthy. The concentrations of the sulphate used are low. Distinct evidence of the toxic effects of the salt, together with only slight decrease in growth in culture 4 of the series is shown. High percent-

ages of calcium and magnesium accompany low growth; low percentages of calcium and magnesium go with much increased growth. No iron could be quantitatively determined in cultures 8 and 9. The copper content shows no variations which may be regarded as important, in fact the amount taken up by the plants is somewhat lower where decreased growth is shown.

Zinc sulphate was used with copper sulphate as shown in table 20. There is little evidence of antagonism between the two salts. At the same time there is evidently no direct relationship between concentration and toxic effect, since growth does not decrease regularly with increasing concentration. While the percentages of calcium and magnesium found are somewhat irregular, they increase rapidly as growth becomes less. The percentage of magnesium found in the tops in culture 8 was 1.10 per cent, and in the roots 1.91 per cent. This occurred with the same concentration of the magnesium ion in the nutrient as in culture 1. The percentage of copper found in the dry matter is distinctly larger than that found in the preceding series, in which copper sulphate alone was used.

Copper sulphate used with ferric sulphate shows no evidence of antagonism between the two if the growth of the tops alone is considered, but with the roots there is a marked increase in growth in cultures 3 and 4 of the series. The percentages of magnesium found in the roots is low and constant, which contrasts markedly with the amounts determined in the previous series. The calcium likewise varies but little in the tops and its percentage remains low. On the other hand, the percentages of calcium in the tops and magnesium in the roots show marked increases as growth decreases. The amount of iron remains very uniform until the last culture of the series is reached, when a marked increase is recorded. It will be noted that the percentage of calcium decreases to nearly one-third of the original in the same culture. This relation has been noted previously in other series.

The stimulation resulting from the addition of ferric sulphate to the nutrient solution in the concentrations given in table 22 is remarkable, a total dry weight of 3.9016 grams for the tops of six plants being recorded. The growth of the roots does not parallel that of the tops. In the highest concentration of ferric sulphate employed, the root growth decreased while the growth of the tops was increased. Attention has already been called to cases of this kind in which there may be an increase in the growth of tops with a decrease in

the root growth, or vice versa. As will be noted, the percentages of calcium and magnesium found are low, in fact below the control in every case. Whether or not ferric sulphate would be stimulating in still higher concentrations is not known, but it is probable that the limit of stimulation was reached, since the roots show a marked decrease in growth in the highest concentration used. The percentage of iron found is comparatively high. The reason for this increased growth is evidently bound up with the presence of the ferric salt, but no idea of the nature of its action can be given. It is very evident from the present data, however, that the amounts of the elements present in the plants were low.

In table 23 the results with zinc sulphate alone are reported. There is no stimulation or no antagonism between zinc sulphate and the other constituents of the solution evident in any concentration. As growth decreases magnesium was found present in larger amounts than in the cultures in which growth was more nearly normal. The percentage of calcium remains very much the same in the tops and decreases rapidly in the roots with decreasing growth. Here we have a suggestion of a relationship between zinc and calcium as has already been referred to in the case of iron. It can only be stated, however, that the results as regards calcium penetration are exceptional in the light of the results in other series previously referred to.

Turning to table 24, in which the results with zinc sulphate and ferric sulphate are given, there is a marked contrast on the one hand with series 20 in which zinc sulphate and copper sulphate were used, and on the other hand with the preceding series in which zinc sulphate alone was used. In this series there is marked antagonism shown between the salts employed. This is true for both tops and roots, but the most marked increase in both does not occur in the same culture. The marked increase in growth of the tops evident in culture 4 is accompanied by a decrease in the percentages of calcium and magnesium present in the tops but not in the roots. The percentage of magnesium in the roots increases with decreased growth throughout the series. The calcium in the tops is low and abnormally so in the roots. Growth is good throughout the series and in culture 4 is increased about 50 per cent above the control. This result would hardly be expected from the decreases recorded where zinc sulphate was used alone in the preceding series. The percentage of iron varies somewhat, but does not increase or decrease with any regularity in any one direction. Attention is again called to the low calcium content, especially of the roots.

Little can be said of the mercuric chloride ferric sulphate series given in table 25. Growth is uniformly low throughout, with considerable variation between duplicate cultures. The percentage of magnesium is very high in the roots and while less in the tops, is much above that of the control. The percentage of calcium is uniformly low in both tops and roots. Attention is called to the fact that no iron could be determined quantitatively, except in the highest concentration of salts used. This condition is striking when the rather large amounts of ferric sulphate in the solution are considered.

A short series is reported in table 26 in which the toxic effects of mercuric chloride when used alone, are evident. There is a decrease in growth with increasing concentration of the added salt and also an increasing percentage of both calcium and magnesium found. The very low ash content given by the plants in this series is of interest and will be discussed below.

External Appearances of the Plants

It seems worth while to note here a few of the more striking appearances of the plants. Since iron salts were purposely excluded from all solutions except those in which it was planned to study their effects, the control plants were of a more or less yellowish green color. Aside from this no differences were noted between control plants grown with or without the addition of a little ferric phosphate to the nutrient.

In every series in which growth was limited by the presence of magnesium salts the roots were short and much thickened. With a high concentration of magnesium in a balanced solution, this effect was not noted however. High concentrations of magnesium were also apparent from the decided yellowing of the older leaves. Excessive amounts of calcium were characterized by the appearance of brown spots or streaks on the leaves.[30]

When any considerable growth was permitted the plants grown in solutions of copper salts were dark green in color.[31] Where growth was good the roots were apparently normal. In several of the higher concentrations used, copper hydroxide was deposited upon the roots, especially about the tips. A suggestion is made that possibly copper may replace iron as a catalyzer in connection with the building or activation of chlorophyll.

[30] Jost, Plant physiology (Oxford, Clarendon Press, 1907), p. 85.

[31] Univ. Calif. Agr. Sci., vol. 1 (1917), pp. 495–588.

Several cultures in which mercuric chloride was used and in which growth was good, displayed the same dark green color as noted for copper salts and the same suggestion as made for the functioning of copper in this color relationship may hold for mercuric salts as well in very dilute solutions.

The color was light green when iron salts were present; with the other salts used no marked external effects were noted.

General Review of Experimental Results

It seems advisable to consider the results reported in the previous tables together, so that the data presented in one table may be more closely correlated with those given in another. It is proposed to do this in the present section and further to discuss briefly the more important relationships shown.

It will be noted in the accompanying tables that there is considerable variation between the controls grown at different seasons of the year. This was to be expected, since conditions in the greenhouse varied between the different growing periods. For this reason it is not possible to compare one series of cultures with another so far as absolute weights of the dry matter are concerned. Within any one series or between series grown at the same time the absolute weights are comparable. This point must be borne in mind in considering the results as a whole. In some cultures, however, growth was stimulated to such an extent as to far surpass any variation between series due to differing external conditions. Such a case is that of series 22, in which ferric sulphate was added to the nutrient solution in varying amounts. In culture 5 of this series, the dry weight was over twice that of any control plants grown during the entire time.

The experimental work with the salts of calcium plus magnesium was rather extensive. McCool[32] has reviewed the previous work with calcium and magnesium salts as related to plants, so a discussion of that phase of the relationships between the two need not be entered into here. In his own work McCool found that calcium chloride was effective in antagonizing the poisonous effects of magnesium chloride and magnesium sulphate. He found a slight increase in the growth of pea seedlings over the controls based upon the green weight of the plants. This was the case in distilled water and in nutrient solution. It seems probable that the nutrient solution used by McCool was not

[32] Cornell Univ. Agr. Exp. Sta. Mem. 2 (1913), p. 129.

a balanced solution, since the addition of either magnesium or calcium chloride resulted in an increased growth of the pea seedlings.

In the present investigation there are only two cases in which the growth of the plants was greater with both calcium and magnesium chlorides present than when calcium chloride was used alone in various concentrations, one in culture 6, series 2, the other in culture 11, series 3. In the latter culture the dry weight of the plants was twice that in the same concentration of calcium chloride alone. There are marked differences in growth recorded between different combinations and concentrations of the two salts, and as can be easily seen from the graphs, the percentages of the two ions found in the plants show an inverse relation to growth in nearly every instance. Proceeding from series to series, the amount of magnesium found in the plants increases with the concentration of the magnesium chloride in the nutrient solution.

Magnesium sulphate is not as toxic as magnesium chloride in equivalent concentrations of the kation. Growth in solutions of magnesium sulphate plus calcium chloride was superior in every case to that found when the salts were used separately. There is a marked contrast between calcium chloride and calcium nitrate in antagonizing the toxic effects of magnesium sulphate, the nitrate proving less effective than the chloride in concentrations of .12 M. and over. This is of especial interest, since the qualitative ionic relations of the nutrient are not altered. It is possible that we are dealing with the effects of undissociated molecules in the higher concentrations, which may be very different from ionic effects.

Results with Salts of the Heavy Metals

Since salts of aluminum, copper, zinc, iron and mercury were used, it will be necessary for the sake of clearness to treat each more or less separately.

Miyake[33] has shown aluminum chloride to be highly toxic, in concentrations above $\frac{N}{7500}$, to rice seedlings grown in water cultures. Similar results have been reported by House[34] and Gies, Micheels and De Heen,[35] Duggar,[36] and Ruprecht,[37] working with several aluminum

[33] Jour. Biol. Chem., vol. 25 (1916), p. 23.
[34] Amer. Jour. Physiol., vol. 15 (1905), p. 19.
[35] Bull. Acad. Roy. Belg. (1905), p. 520.
[36] Plant Physiology, New York, Macmillan, 1911.
[37] Mass. Exp. Sta. Bull. 161 (1915), p. 125.

salts. Probably the work of Abbott, Conner and Smalley[38] is of more direct interest here. These investigators found aluminum nitrate to be toxic to corn seedlings in the presence of nutrient solutions. E. Kratzmann[39] has reported stimulation due to the presence of small amounts of aluminum salts. Miyake[40] concludes further that the effects observed with aluminum chloride cannot be attributed to the hydrogen ion resulting from the dissociation of the salt.

Aluminum chloride was found to be toxic in every concentration used in the present work. The effect of the presence of calcium chloride in a concentration of .20 M. was to decrease growth still further, indicating that its toxic effect, as reflected in growth, was but additive to that of aluminum chloride. With magnesium chloride present in equivalent concentration as the calcium chloride, there is a marked antagonism at a concentration of .000066 M. of aluminum chloride with .20 M. magnesium chloride. The increase in dry weight was 100 per cent greater than in an equivalent concentration of aluminum chloride alone and 300 per cent greater than with magnesium chloride in the concentration given. This culture has been referred to especially since it furnishes a striking example of antagonism between bivalent and trivalent salts, both of which are highly toxic when used alone. The chloride ion was a constant as far as this and the preceding series are concerned, the only difference between the two cases being the use of calcium chloride in one and magnesium chloride in the other. It seems logical to conclude that the action is specific as regards the magnesium and aluminum ions. Whatever the nature of this action may be, it is certainly not shown between calcium and aluminum ions.

The same general relationships are brought out between ferric chloride and calcium and aluminum chlorides. Ferric chloride did not prove toxic in the concentrations used, growth differing but little from that of the control. When calcium chloride was present in a concentration of .20 M. throughout the series, growth was half or less than half that recorded when ferric chloride alone was present. Magnesium chloride in equivalent concentrations, as the calcium chloride above, affected growth but little. In other words, magnesium chloride did not prove toxic in the presence of certain concentrations of ferric chloride. The relations between the four salts may be briefly summarized as follows: There is no antagonism shown between alumi-

[38] Ind. Exp Sta. Bull. 170 (1913), p. 329.

[39] Chem. Ztg., vol. 38 (1914), p. 1040.

[40] Jour. Biol. Chem., vol. 25 (1916), p. 23.

num chloride and calcium chloride. There is very little, if any, between ferric chloride and calcium chloride. Magnesium chloride and ferric chloride show marked antagonism in all concentrations used as do magnesium chloride and aluminum chloride in certain concentrations of the two salts. Magnesium chloride and ferric chloride show marked antagonism in all concentrations as do magnesium chloride and aluminum chloride in one concentration of the latter salt.

Reference has already been made to Miss Brenchley's monograph[41] and to the paper by Lipman and Gericke,[42] in which the literature relating to the effects of copper, zinc, and iron salts on plants is reviewed. Suffice it to say that the results reported by different investigators are very conflicting, due largely to the widely different methods used and the varying conditions under which the various data were obtained.

In the present work, copper chloride was toxic in every concentration used. There was marked antagonism between copper and ferric chlorides both from the standpoint of growth and of absorption.

Copper sulphate did not prove to be uniformly toxic. Growth was nearly normal in one concentration used while very much diminished in a lower concentration. The term stimulation might be applied here, but in the present discussion it is applied only when growth due to the presence of an added salt or salts is undoubtedly greater than that in the control.

Toxic effects are correlated with increased absorption and antagonistic effects with decreased absorption as in other series reported.

Growth was always less with zinc sulphate present in the nutrient solution than in the latter alone. Copper and zinc sulphate together were no more toxic than a solution of zinc sulphate alone.

The case with ferric sulphate is clearly one of stimulation. The dry weight was over twice that of the controls in one concentration of the salt used and far superior in several concentrations to that of the plants grown in the controls. Wolff[43] has reported similar results when iron was used in the form of the citrate, an increase in growth comparable to that noted above having been obtained. He found further that nickel or chromium could not be used to replace iron.

The toxic effects of copper sulphate were markedly reduced by the presence of ferric sulphate when we consider the results as a

[41] Inorganic plant poisons and stimulants. 1915.

[42] Univ. Cal. Pub. Agr. Sci., vol. 1 (1917), p. 395.

[43] C.-R. Acad. Sci. (Paris), vol. 157 (1913), p. 1022.

whole, although in one instance growth was greater with copper sulphate alone than when both salts were added together.

The second case of stimulation was noted with zinc sulphate and ferric sulphate in certain concentrations. In series 26 four cultures gave growth superior to that obtained in the control for the series, and throughout growth was good when the two salts referred to above were present together, over the range of concentrations employed. Low absorption was noted. In summarizing the relations of ferric, cupric and zinc sulphates, it is evident, from the discussion above, that zinc sulphate was toxic in every concentration used. Copper sulphate was toxic, but marked variation in degree was shown between various concentrations. Ferric sulphate was stimulating. Copper sulphate and zinc sulphate were no more toxic together than when each was used alone. Ferric sulphate modified somewhat the toxic effects of copper sulphate. Zinc sulphate and ferric sulphate together proved stimulating to the growth of plants. As contrasted with the chlorides, the sulphates of copper and iron were less toxic to barley over the range of concentrations used in this investigation.

Taking the results as a whole, twelve instances of a marked increase in growth at certain definite concentrations of one or more added salts have been noted. With every such increase there is a very notable decrease in the amount of calcium and magnesium absorbed. The increase in growth is attributed to antagonistic salt action; decreased absorption is undoubtedly due to the same action, which tends to preserve the normal permeability of the plasma membrane.

In addition to the twelve instances referred to above, we find in series after series, the toxic effects of the solution in which the plants were growing, noticeable not alone by decreased growth but also by increased absorption. The roots and tops may not show the same relations as regards the amounts of calcium and magnesium taken up. For example, in series 25, in which ferric sulphate and mercuric chloride were used together, the toxicity of the solutions was evident by the very limited growth, yet the composition of the tops was about normal. In the roots, however, the percentage of magnesium was found to be tremendously increased.

It is of interest to refer again to the very low ash content and relatively low absorption, considering the very limited growth, in the few cultures in which mercuric chloride was used alone. It is possible that relatively large amounts of mercuric salts were taken up by the plants which were volatilized on ashing the residue; thus the low percentage of ash may be less surprising.

Possible Effects of Variations in the Concentrations of the Solutions on the Plants

No attempt was made to maintain the total concentration of the nutrient solution constant. This would be exceedingly difficult to do in work of this character, since it would be necessary to vary the concentration of the nutrient solution to maintain the balance of the solution as regards total concentration. The conclusion seems justified that within the range employed the concentration of the nutrient solution is of minor importance as far as growth is concerned. For instance, in table 1, the variation in the concentration of the solution was .279 M. in terms of calcium chloride, yet the total growth varied but little from .001 M. to .28 M. Again in table 2 the growth is very nearly the same at a concentration of .25 M.. with calcium and magnesium chlorides, and a total concentration of .54 M. of the same salts. In table 3 the greatest growth occurred in a concentration of .46 M. in terms of the salts above mentioned, while at the lower concentrations of .304 M., growth was but a third that obtained in the higher concentrations. These examples make clear the point above mentioned, namely, that the concentration over the range used was of but minor importance. It is obvious that the above discussion does not apply to the series in which salts of the heavy metals were used, since the variations in concentration in those series were but slight.

Consideration of a Possible Calcium-Magnesium Ratio

Since Loew[44] first advanced the hypothesis of the lime-magnesia ratio, much experimental evidence has been collected by various investigators both for and against the existence of an optimum ratio between these two elements as regards the growth of plants. The literature bearing upon the subject has been very fully reviewed by Lipman,[45] so that detailed references are not necessary here.

Since the ratios of calcium to magnesium in the solution used by the writer were known and also because of the fact that the analytical data allowed of the calculation of such a ratio for the plants, it seemed of interest to present some of these data here.

The following two tables give the results obtained from two series in which widely varying proportions of calcium and magnesium were used.

[44] Flora, vol. 75 (1892), p. 368.

[45] Plant world, vol. 19 (1916), p. 83.

TABLE 27

Ratio Mg to Ca in solution	Dry weight tops	Ratio Mg to Ca in tops	Dry weight, roots	Ratio Mg to Ca in roots
41 : 1	.3536	2.3 : 1	.1218	1.2 : 1
16 : 1	.5484	4.6 : 1	.1519	1 : 2
8 : 1	.5885	6.0 : 1	.1266	1 : 1
4.1 : 1	.4774	2.6 : 1	.1509	3.3 : 1
2.7 : 1	.3433	2.6 : 1	.1497	1.2 : 1
2.0 : 1	.6775	2.7 : 1	.2119	1.3 : 1
1.6 : 1	.4136	1.2 : 1	.1500	1.3 : 1
1.3 : 1	.4431	1 : 1.2	.1421	1.2 : 1
1 : 1	.3745	1.3 : 1	.1138	1 : 1.3
1 : 1.2	.3268	1.5 : 1	.1254	1 : 1.5
1 : 1.4	.2815	1.8 : 1	.1053	1 : 1.2
1 : 1.8	.5030	1 : 1.2	.1044	1.2 : 1

Table 27 was computed from the results given in table 2. Magnesium chloride was present in uniform concentration of .24 M. with varying concentrations of calcium chloride.

It will be noted that the dry weights with a ratio of magnesium to calcium of 16 : 1, 8 : 1, and 1 : 18 are nearly the same. The ratios of these two elements found in the plants grown in these solutions were 2 : 1, 1 : 1, 1 : 1.2 for the roots, and 1 : 4.6, 1 : 1.6, 1 : 1.2 for the tops. Further, the dry weight of plants grown in a solution in which the ratio was 41 : 1 and with a ratio of 1 : 1 are nearly the same. It is evident that the same ratio for the roots may not hold for the tops.

TABLE 28

Ratio Mg to Ca in solution	Dry weight, tops	Ratio Mg to Ca in tops	Dry weight, roots	Ratio Mg to Ca in roots
20.2 : 1	.3033	5.5 : 1	.0822	4.4 : 1
10.5 : 1	.4716	5.4 : 1	.1572	4.7 : 1
6.8 : 1	.2799	4.8 : 1	.0780	6.3 : 1
5.1 : 1	.1999	5.8 : 1	.0342	6.0 : 1
4.0 : 1	.1999	4.8 : 1	.0636	7.4 : 1
3.4 : 1	.4363	1.3 : 1	.1122	4.1 : 1
2.5 : 1	.4013	1.8 : 1	.1143	2.8 : 1
2.0 : 1	.2734	2.3 : 1	.0677	4.7 : 1
1.7 : 1	.2603	2.5 : 1	.0867	6.8 : 1

Table 28 gives the ratios in the solutions used in series 4, in which the ratios of magnesium to calcium varied from 20.2 : 1 to 1.7 : 1. Growth is nearly the same in solutions in which the ratio was 10.5 : 1 as in those in which the ratio is 3.4 : 1 or 2.5 : 1. The plants grown in these cultures gave the following values for the tops: 5.4 : 1, 3.4 : 1, 2.5 : 1, and for the roots, 4.7 : 1, 4.1 : 1, and 2.8 : 1. There is a tendency for the ratio of calcium to magnesium in the plants to become narrower

as the ratio of these two ions in the solution becomes narrower. Where a wide ratio exists in the solution, there is always a much narrower ratio in the plants.

From the brief discussion above it is evident that the barley plants grew equally well in solutions having widely different ratios of calcium and magnesium ions. There is no "optimum lime-magnesia ratio," as Gile[46] and Wyatt[47] as well as others have shown, and their results are confirmed in the present investigation.

The balance between all the ions present in the solution appears to be of far greater importance than any single ratio. A consideration of the ratios existing between the various ions of the nutrient solution, aside from calcium and magnesium used, is reserved for further study.

Permeability and Antagonism

It is not proposed to enter into a discussion of the structure and composition of the plasma membrane. Davidson[48] has recently summarized our present knowledge concerning it with special reference to selective permeability. A discussion of the various theories which have been advanced to explain antagonistic salt action need not be taken up in detail here. The reader is referred to papers by Clark,[49] Loeb,[50] Osterhout,[51] Loew,[52] Koenig and Paul,[53] True and Gies[54], True and Bartlett,[55] Kearney and Cameron,[65] and Ostwald[57], for a discussion of the various factors which may be of importance in this connection.

The recent work of Clowes[58] and Fenn[59] is important and some very striking similarities between the action of toxic and antagonistic solutions on oil emulsions and on gelatine on the one hand, and plant cells on the other, have been reported by these investigators.

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46 Porto Rico Exp. Sta., Bull. 12 (1912).
47 Jour. Agr. Research, vol. 6 (1916), p. 589.
48 Plant World, vol. 19 (1916), p. 331.
49 Bot. Gaz., vol. 33 (1902), p. 26.
50 Archiv. ges. Physiol., vol. 88 (1902), p. 68.
51 Science, n.s., vol. 35 (1912), p. 112.
52 Flora, vol. 75 (1892), p. 368.
53 Zeitschr. Hygiene u. Infektionskrankheiten, vol. 25 (1897), p. 1.
54 Bull. Torr. Bot. Club, vol. 30 (1903), p. 390.
55 U. S. Dept. Agr., Bull. 231, 1912.
56 U. S. Dept. Agr., Bull. 71, 1902.
57 Archiv. ges. Physiol., vol. 120 (1907), p. 19.
58 Jour. Phys. Chem., vol. 20 (1916), p. 407.
59 Proc. Nat. Acad. Sci., vol. 2 (1916), p. 539.

To define normal permeability is very difficult. There seems to be a comparatively wide range of concentration of salts over which the amount of any element taken up may vary without affecting the growth of the plant to any considerable extent. There is likewise a wide range over which the ratio of any one element to any other may change without being detrimental to plant growth. The latter point has been discussed above in connection with a possible optimum calcium-magnesium ratio for plants. The first point referred to has been very well treated by Gile and Ageton,[60] so that further reference need not be given here.

For the work in hand the percentage composition of the plants grown in the control cultures seemed to be the most logical criterion of normal permeability available. There are variations between the controls as regards composition, but they are relatively small. On the other hand, the percentages of magnesium, for instance, range from .02 per cent to 9.21 per cent, depending upon the solution used. The percentages of calcium differ over a wide range as well. From the data presented there can be no doubt whatever that the composition of the plant, as regards inorganic constituents at least, may be altered enormously by variations in the surrounding solution.

That portion of the root system in any plant which functions as a semipermeable membrane is obviously of greatest importance in a study of the present kind. The actual area of the membrane which is in contact with the solution must be known in every case before it can be said that the permeability of one root system is greater than that of another. The actual area of the plasma membrane cannot be measured directly because, in the first place, we have no means of determining just how much of the root is involved, and secondly, the area concerned may be changing continually.

Length of the roots and their number and length together as well as green weight and dry weight have been taken as criteria of the existence of antagonism. In the present paper the dry weight has been taken as proportional to the area of the plasma membrane through which salts may enter the plant. It cannot be stated definitely that the two are proportional. They have only been so considered since the dry weight of the plant was the most logical criterion to employ. The reservation must always be made that the two may not be directly proportional, even though they are treated as being so.

That the permeability of the plasma membrane of the plant cells

[60] Porto Rico Agr. Exp. Sta. Bull. 16, 1914.

is changed by the nature and balance of the solution surrounding the roots there can be no doubt from the data already given. That a number of ions are capable of acting in a very similar manner to one another as regards permeability is also evident from the present work. Further. the same salt may act differently at different concentrations, preserving nearly normal permeability at some and allowing the penetration of large numbers of ions at others. As previously stated, the total balance of the solution is of vital importance in the preservation of normal permeability, which is in turn correlated with normal growth.

In connection with the salts of the heavy metals, the amounts of the kation of cupric and ferric salts which had penetrated the plant tissue were determined in a number of instances. The percentages found were low. Further, whenever these salts proved toxic, the amounts of calcium and magnesium found in the plants were high; high enough in fact to account for the toxic effect alone. In many instances the percentages of those two elements found were as high in toxic solutions of copper, iron, or zinc salts as when toxic concentrations of calcium or magnesium chlorides were used. We might, therefore, in the light of our present knowledge, be justified in attributing the decreased growth of the plants to the abnormally high absorption of calcium and magnesium and the consequent reactions taking place within the plant cells. The permeability of the membrane must be altered to allow of the presence of these ions in large numbers. The toxic effects due to the presence of large amounts of calcium or magnesium salts might be evident if we could inject solutions of these salts into the plant without altering the permeability of the plasma membrane. But from the present data it seems that the alteration in the permeability of the membrane is the essential consideration.

It is probable also that the toxicity of any solution is accompanied by the increased permeability of the plant tissue to all inorganic salts which are normally found in plants. There may be exceptions as noted already for iron and calcium, but in general this relation holds from the data now at hand.

Ruprecht[61] has localized the effects of aluminum salts in the few layers of cells surrounding the root hairs and attributes the death of the plants grown in solutions of aluminum salts to starvation incident upon the inability of the plant to obtain nutrient salts for normal

[61] Mass. Exp. Sta. Bull. 161 (1915), p. 125.

metabolism. Forbes[62] has likewise localized the effects of copper salts, when present in toxic concentrations, and concludes that the toxic effect of copper is due to the combination of metal with protein at the growing tips of the roots.

From the experimental results given in the present paper, it is evident that the presence of the salts of each element in toxic concentration results in an increased permeability of the plant tissues to calcium and magnesium at least. Ruprecht's view that plants starve for lack of nutrient salts when grown in toxic solutions is untenable, in the light of the above discussion.

The results of both investigators are significant in indicating the localization of the effect of the two metals studied in the extreme outer portion of the roots, in which the plasma membrane is located.

The results obtained by Loeb with Fundulus eggs, by Osterhout with Laminaria, using electrical conductivity methods, and by Brooks employing microscopical methods with various plant tissues, all point to the preservation of normal permeability as the result of antagonistic salt action. The results reported by these investigators using widely different methods have been confirmed in the present work by the use of a more direct and more nearly quantitative method than any hitherto employed.

It must be recognized, however, that a picture of but one stage in the growth of the plant has been given and that only a portion of the inorganic constituents have been determined. The results reported are essentially those of a static system and must be so considered in comparing them with results obtained by the use of other methods referred to above.

Summary

In the present paper results are given showing the effect of various salt solutions upon the chemical composition of plants, with special reference to a correlation between toxic and antagonistic effects and composition. A uniform nutrient solution was used throughout. The cultures were arranged in series in which the concentration of one salt was kept constant while the concentration of a second salt varied over a wide range. In several series the concentration of both varied, but the ratio between the two remained constant. The analytical data cover the percentages of calcium and magnesium found in the plants grown in every culture, together with determinations

[62] Univ. Cal. Publ. Agr. Sci., vol. 1 (1917), p. 395.

of potassium, iron and copper in certain series. With these facts in mind the results of the investigation may be briefly stated as follows:

The composition of the plants grown in different solutions varied widely.

Normal growth, i.e., approximately that of the controls, was always accompanied by approximately equal percentages of calcium and magnesium in the plants.

In nearly all cases in which the growth of the plants was decreased to a marked extent, the amounts of the two elements referred to above were increased greatly.

The degree of absorption of any salt seems to be independent of the concentration present in the solution over a wide range.

Certain relationships are pointed out between calcium and magnesium absorption and the presence of iron and zinc salts in the solution.

Antagonism as evidenced by growth is correlated with absorption of the ions, which were determined, in every instance.

Stimulation of growth was recorded when ferric sulphate was present in the nutrient solution in certain concentrations and with ferric sulphate and zinc sulphate together.

The amounts of the two ions uniformly determined were not necessarily found in the same proportions in roots and tops.

The possible effects of changes in concentrations of the various solutions are considered, and the conclusion reached that the changes in concentration were of secondary importance over the range of concentrations of the various salts used.

Data are presented showing that growth is the same with widely varying ratios of calcium to magnesium in the nutrient solution.

The results in general confirm those of Loeb, Osterhout, and Brooks in finding that antagonistic salt action tends toward the preservation of normal permeability of the plasma membrane in living tissue.

This problem was suggested by Dr. C. B. Lipman. The writer wishes to express his thanks for this and for many other valuable suggestions offered while the work was in progress. The writer is also indebted to Prof. L. T. Sharp for helpful advice.

NOTE

The following key applies to all the graphs. The numbers on the abscissas represent both the actual weight of tops and roots and percentages of calcium and magnesium, or of iron, when the latter were plotted. The numbers on the ordinates correspond to the number of cultures as given in the table on the opposite page. The heavy lines always refer to the roots, the light lines to the tops.

The following type lines are used:

——————————————————— (Solid line) Weight of tops.
— — — — — — — — — — — — (Short dashes) Weight of roots.
—— —— —— —— —— —— —— (Long dashes) Percentage of calcium.
—— — — (One long and two short dashes) Percentage of magnesium.
—— — (One long and one short dash) Percentage of iron.

The numbers given in the "Explanation of Plates" always refer to the plants arranged in order from left to right, the control being on the extreme right in every case.

TABLE 1

Calcium Chloride

No.	Solution $CaCl_2$	Dry weight	Mean	Percentage of Ash	Mean	Percentage of Ca	Mean	Percentage of Mg	Mean
1	.002	Tops .7633		15.38		.477		.051	
		.7104	.7368	15.34	15.36	.....	.477	.046	.049
		Roots .3608	.1804	26.24		.231		.413	
2	.004	Tops .6486		15.34		.400		.116	
		.4976	.5731	17.34	16.34	.470	.435	.154	.135
		Roots .6555	.3277	29.98		.261		.507	
3	.01	Tops .6419		17.29		.514		.095	
		.6138	.6279	16.81	17.05	.517	.515	.078	.086
		Roots .5628	.2814	28.10		.219		.498	
4	.02	Tops .4814		16.80		.504		.045	
		.6600	.5707	17.69	17.24	.450	.477	.044	.045
		Roots .5750	.2875	31.56		.121		.483	
5	.04	Tops .5950		17.52		.640		.048	
		.5442	.5696	16.59	17.05	.565	.602	.044	.046
		Roots .5959	.2979	33.54		.113		.563	
6	.06	Tops .5692		17.67		.718		.050	
		.4998	.5845	17.00	17.33	.713	.715	.087	.069
		Roots .5048	.2524	29.45		.098		.420	
7	.08	Tops .6706		13.92		.407		.035	
		.5015	.5860	11.82	12.87	.684	.545	.079	.057
		Roots .5250	.2625	29.46		.363		.472	
8	.10	Tops .6114		18.46		.428		.061	
		.4182	.5148	19.94	19.20	.440	.434	.068	.064
		Roots .3827	.1913	30.18		.290		.652	
9	.12	Tops .4832		16.80		.443		1.000	
		.4778	.4805	17.15	16.97	.425	.434	.82	.962
		Roots .3918	.1959	29.12		.273		.810	
10	.16	Tops .5668		17.45		.387		1.340	
		.5218	.5443	18.47	17.96	.486	.436	1.300	1.32
		Roots .6123	.3066	29.43		.392		.415	
11	.20	Tops .5687		17.03		.348		.358	
		.7637	.6662	17.13	17.08	.388	.368	.282	.320
		Roots .6305	.3154	31.82		.204		.407	
12	.24	Tops .5266		17.62		.354		.316	
		.5793	.5529	17.34	17.48	.392	.373	.137	.226
		Roots .6067	.3033	27.08		.373		.577	
Full Nutrient		Tops .7937		18.80		.393		.235	
		.7418	.7677	19.10	18.95	.390	.391	.202	.218
		Roots .6900	.3450	20.03		.227		.259	

Grown October 24–December 5, 1915.

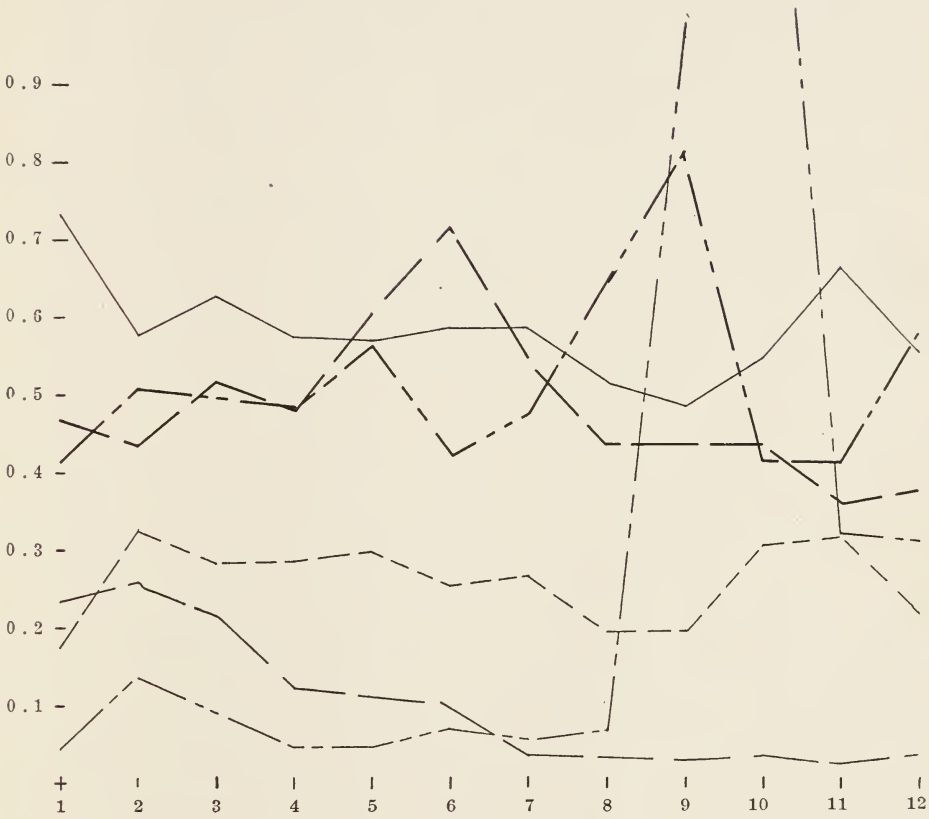

Fig. 1
Calcium Chloride
(See Table 1)

TABLE 2

Magnesium Chloride + Calcium Chloride

No.	Solution $MgCl_2$	Solution $CaCl_2$		Dry Weight	Mean	Percentage of Ash	Mean	Percentage of Ca	Mean	Percentage of Mg	Mean	Percentage of Fe	Mean
1	.24	.004	Tops	.3407		12.90		.483		1.21		.....	
				.3666	.3536	13.00	12.95	.500	.491	1.06	1.16	.....	
			Roots	.2456	.1218	20.05		.557		.670		.022	
2	.24	.01	Tops	.5106		16.84		.198		.883		.....	
				.5862	.5484	16.88	16.86	.196	.197	.953	.918	.....	
			Roots	.3038	.1519	16.75		.437		.216		.025	
3	.24	.02	Tops	.2758		15.22		.490		1.45		.....	
				.5885	.4321	15.94	15.58	.189	.339	1.09	1.13	.....	
			Roots	.2533	.1266	21.02		.407		.433		.010	
4	.24	.04	Tops	.4450		16.30		.361		.967		.943	
				.4828	.4619	.17.55	16.92	.342	.351	.920	.943	.....	
			Roots	.3018	.1509	16.32		.550		1.82		.009	
5	.24	.06	Tops	.3150		18.50		.445		1.07		.....	
				.3716	.3433	17.87	18.18	.403	.422	1.13	1.10	.....	
			Roots	.2994	.1497	19.54		.309		.388		.006	
6	.24	.08	Tops	.6871		15.97		.154		.440		.....	
				.6679	.6775	.....	15.97	.172	.163	.441	.440	.....	
			Roots	.4238	.2119	14.25		.206		.280		.007	
7	.24	.10	Tops	.4797		16.75		.458		.645		.....	
				.4476	.4636	13.23	14.99	.457	.457	.507	.576	.....	
			Roots	.3000	.1500	19.95		.430		.577		.002	
8	.24	.12	Tops	.4583		16.20		.817		.665		.....	
				.4279	.4431	17.43	16.81	.732	.774	.635	.650	.....	
			Roots	.2843	.1421	23.09		.376		.454		.006	
9	.24	.16	Tops	.3243		15.14		1.160		1.46		.....	
				.3543	.3393	15.45	15.29	1.210	1.18	1.59	1.52	.....	
			Roots	.2276	.1138	24.60		.970		.714		.010	
10	.24	.20	Tops	.3404		16.62		1.140		1.69		.....	
				.3132	.3268	17.50	17.06	1.330	1.23	1.98	1.83	.....	
			Roots	.2508	.1254	24.60		1.200		.785		.012	
11	.24	.24	Tops	.2707		18.53		1.640		.807		.015	
				.2924	.2815	17.83	18.18	1.290	1.46	.826	.816	.009	.012
			Roots	.2107	.1053	24.62		1.200		.995		.010	
12	.24	.30	Tops	.4834		18.48		.563		.675		.010	
				.5226	.5030	17.64	18.06	.585	.574	.707	.691	.012	.012
			Roots	.3888	.1944	25.16		.437		.538		.010	
13	.24		Tops	.4281		16.83		.387		.907		.018	
				.5106	.4693	17.20	17.02	.383	.385	.890	.898	.013	.015
			Roots	.2463	.1231	23.07		.208		.800		.011	

Grown January 2–February 13, 1916.

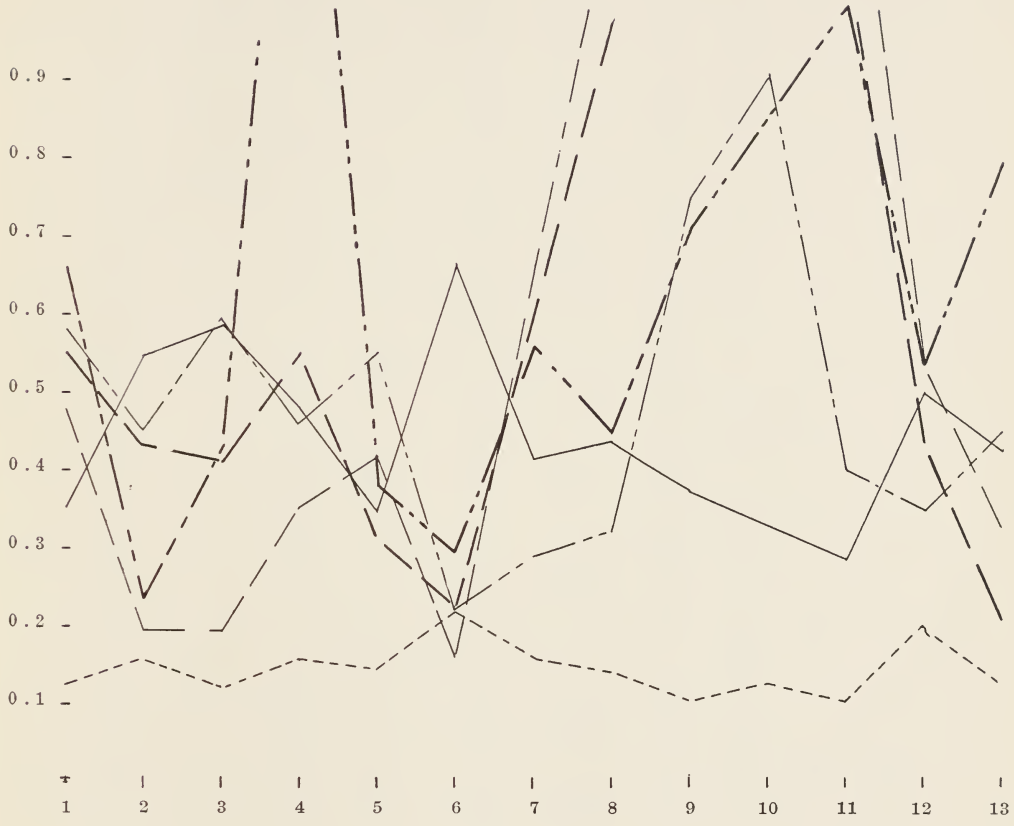

Fig. 2
Magnesium Chloride + Calcium Chloride
(See Table 2)

TABLE 3

Magnesium Sulphate + Calcium Chloride

No.	Solution $MgCl_2$	Solution $CaCl_2$	Dry Weight	Mean	Percentage of Ash	Mean	Percentage of Ca	Mean	Percentage of Mg	Mean
1	.30	.001	Tops .1986		16.60		.300		.440	
			Roots .2650	.2318	15.60	16.10	.209	.259	.413	.426
2	.30	.002	Tops .2700		16.44		.198		.571	
			Roots .2766	.2733	16.39	16.41	.143	.170	.514	.542
3	.30	.004	Tops .2566		18.43		.216		.595	
			Roots .2236	.2401	17.39	17.91	.274	.255	.533	.564
4	.30	.01	Tops .3194		16.49		.229		.515	
			Roots .1744	.2469	14.28	15.38	.189	.209	.088	.515
5	.30	.02	Tops .2074		14.56		.526		.749	
			Roots .2249	.2163	15.73	15.14	.....	.526	.565	.607
6	.30	.04	Tops .5249		15.19		.423		.405	
			.4166	.4707	15.57	15.38	.396	.409	.437	.418
			Roots .1309	.0654	18.10		.443			
7	.30	.06	Tops .3036		16.83		.254		.649	
			.1836	.2436	17.42	17.12	.145	.254	.790	.719
			Roots .0850	.0425	14.70		.263			
8	.30	.08	Tops .2184		17.90		.235		.700	
			.2403	.2293	15.99	16.94	.213	.224	.663	.681
			Roots .0648	.0324	13.05		.104		.230	
9	.30	.10	Tops .3978		30.08		.525		1.15	
			Roots			30.08		.525		1.15
10	.30	.12	Tops .3842		17.92		.329		.399	
			.2759	.3300	19.57	18.74	.388	.358	.563	.481
			Roots .1059	.0529	27.29		.623		.124	
11	.30	.16	Tops .8819		17.41		.136		.047	
			.9600	.9209	18.11	17.76	.184	.160	.037	.042
			Roots .6900	.3450	33.71		.435		.047	
12	.30	.20	Tops .2100							
			Roots .2700	24.00		14.08		1.390		3.660
13	.30	.24	Tops .2576							
			Roots .1930	.2253		15.40		1.490		4.210
14	.30	.30	Tops .2600							
			Roots .2000	.2300		14.30		2.200		3.790
Full Nutrient			Tops .7937		18.80		.393		.235	
			.7418	.7677	19.10	18.95	.390	.391	.202	.218
			Roots .6900	.3450	20.03		.227		.259	

Grown October 24 to December 5, 1915.

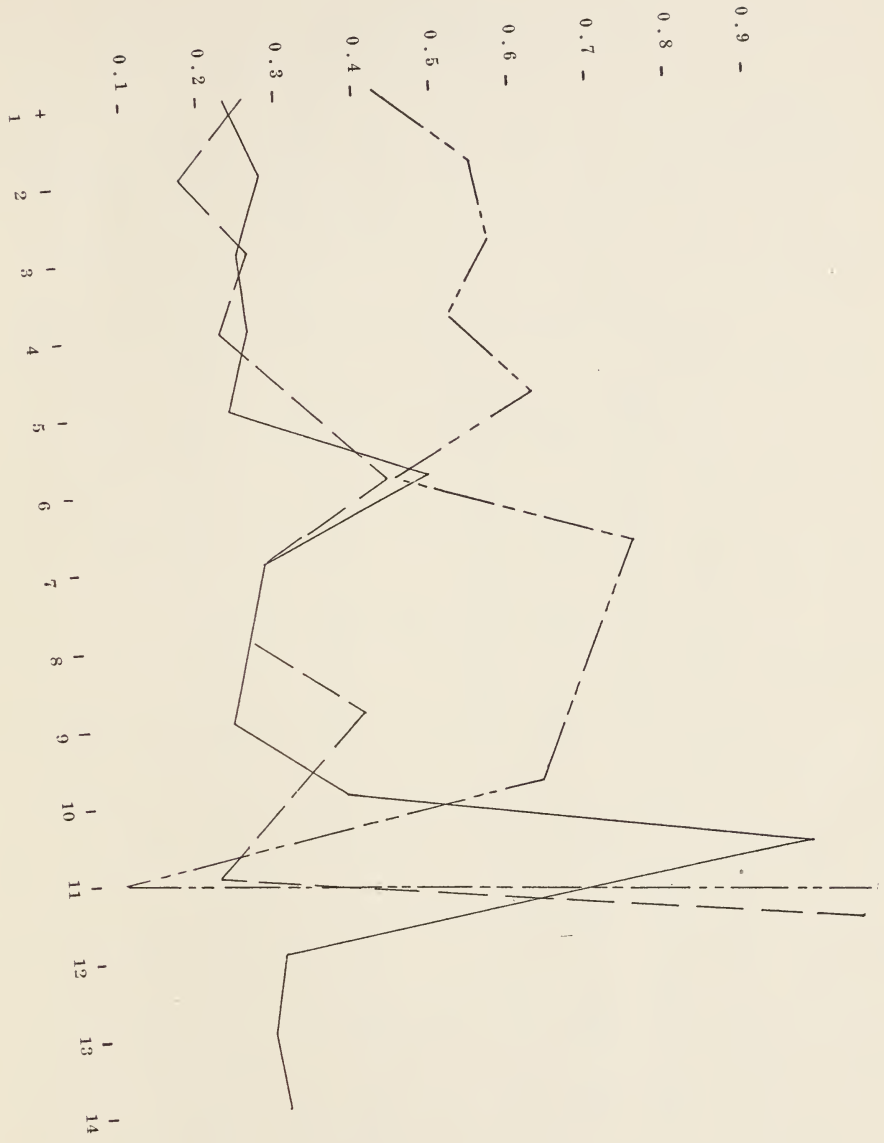

Fig. 3
Magnesium Chloride + Calcium Chloride
(See Table 3)

TABLE 4

Magnesium Chloride + Calcium Chloride

No.	Solution $MgCl_2$	Solution $CaCl_2$	Dry Weight		Mean	Percentage of Ash	Mean	Percentage of Ca	Mean	Percentage of Mg	Mean	Percentage of Fe	Mean
1	.36	.02	Tops	.2878		18.24		.271		1.71			
				.3189	.3033	17.12	17.68	.311	.291	1.51	1.61		
			Roots	.1644	.0822	18.15		.221		.98			
2	.36	.04	Tops	.4128		18.25		.374		1.89		.039	
				.5210	.4716	16.55	17.40	.342	.358	1.99	1.94	.047	.043
			Roots	.3144	.1572	20.65		.263		1.24			
3	.36	.06	Tops	.2952		16.31		.431		2.14			
				.2640	.2799	17.21	16.76	.392	.461	2.37	2.25		
			Roots	.1560	.0780	17.90		.472		3.00			
4	.36	.08	Tops	.1878		18.10		.394		2.22			
				.2034	.1999	.2400	21.05	.407	.400	2.48	2.35		
			Roots	.0684	.0342	17.80		.733		4.43			
5	.36	.10	Tops	.2292		15.13		.532		2.90			
				.1698	.1999	16.20	15.66	.614	.573	2.61	2.75		
			Roots	.1272	.0636	17.90		.631		4.71			
6	.36	.12	Tops	.4788		14.60		.817		.890		.042	
				.3938	.4363	13.65	19.12	.625	.721	1.02	.95	.027	.034
			Roots	.2244	.1122	17.60		.813		3.33		.....	
7	.36	.16	Tops	.3616		14.12		.832		1.23			
				.4410	.4013	15.17	14.64	.742	.787	1.72	1.47		
			Roots	.2287	.1143	16.00		.873		2.47			
8	.36	.20	Tops	.2963		13.21		.931		2.01			
				.2505	.2734	12.17	12.69	.871	.931	2.32	2.16		
			Roots	.1355	.0677	16.99		1.020		4.82			
9	.36	.24	Tops	.3100		14.21		.870		2.31			
				.2106	.2603	13.17	13.69	1.200	1.03	3.02	2.66		
			Roots	.1734	.0867	14.20		.713		4.89			
Full Nutrient			Tops	.7819		20.40		.349		.223			
				.7459	.7639	19.70	20.05	.330	.339	.268	.295		
			Roots	.6209		21.70		.242		.248			

Grown January 7–February 21, 1916.

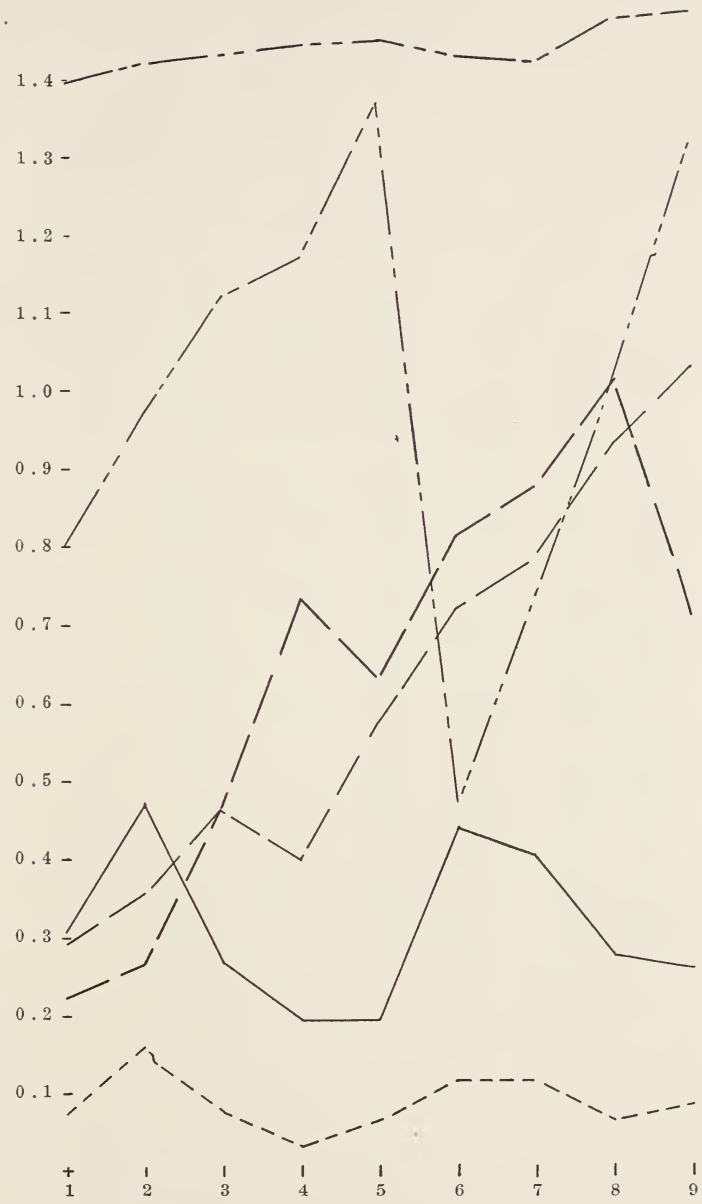

Fig. 4
Magnesium Chloride + Calcium Chloride
(See Table 4)

TABLE 5

Magnesium Sulphate

No.	Solution $MgSO_4$	Dry Weight		Mean	Percentage of Ash	Mean	Percentage of Ca	Mean	Percentage of Mg	Mean
1	.06	Tops	.7326		16.78		.358		.785	
			.7838	.7587	16.46	16.62	.379	.368	.750	.767
		Roots	.6383	.3191	16.84		.495		.550	
2	.10	Tops	.7150		15.73		.302		.320	
			.9420	.8276	16.21	15.97	.313	.307	.320	.320
		Roots	.4822	.2411	22.91		.580		1.270	
3	.14	Tops	.6888		15.09		.201		.350	
			.6546	.6717	15.64	15.36	.230	.215	.390	.370
		Roots	.4437	.2218	20.31		.148		.740	
4	.16	Tops	.3042		12.65		.337		.350	
			.3657	.3349	11.81	12.23	.331	.334	.310	.330
		Roots	.0762	.0381	21.52		.985		1.01	
5	.18	Tops	.2875		12.32		.496		.280	
			.2978	.2926	12.72	12.52	.371	.434	.310	.295
		Roots	.0542	.0271	20.49		1.130		1.300	
Full Nutrient		Tops	.7819		20.40		.349		.223	
			.7459	.7639	19.70	20.05	.330	.339	.268	.295
		Roots	.6209		21.70		.242		.248	

Grown December 9–January 20, 1915–16

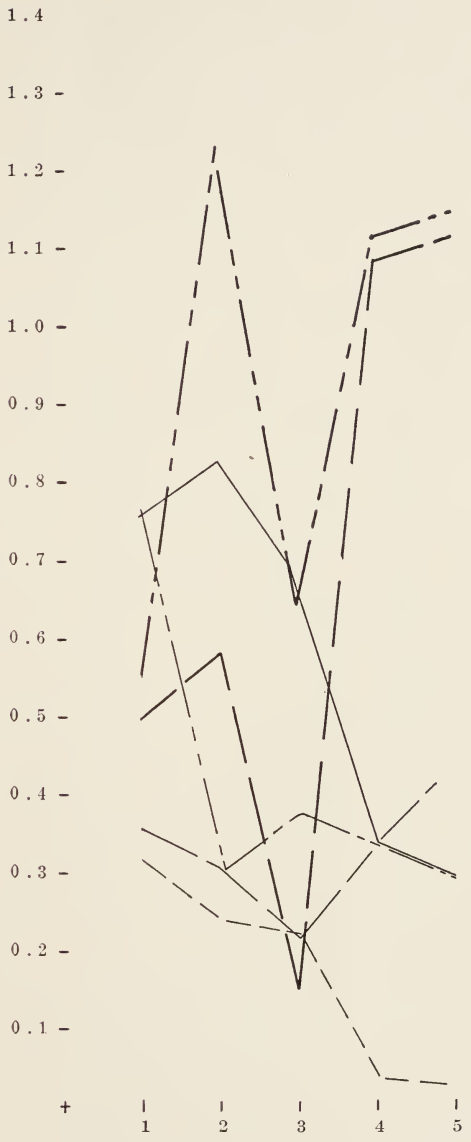

Fig. 5
Magnesium Sulphate
(See Table 5)

TABLE 6

Magnesium Chloride + Calcium Chloride

No.	Solution $CaCl_2$	Solution $MgSO_4$		Dry Weight	Mean	Percentage of Ash	Mean	Percentage of Ca	Mean	Percentage of Mg	Mean	Percentage of Fe	Mean
1	.04	.18	Tops	1.1626		19.91		.261		.407		.036	
				1.2526	1.2076	19.75	19.83	.332	.296	.722	.564	.023	.030
			Roots	.9895	.4942	16.52		.030		.312		.017	
2	.08	.18	Tops	1.1888		20.43		.312		.077		.060	
				1.0948	1.1418	21.15	20.79	.377	.344	.084	.081	.060	.060
			Roots	.9037	.4518	26.13		.151		.180		.020	
3	.12	.18	Tops	1.1287		19.50		.275		.021		.024	
				1.2691	1.1989	21.22	20.36	.276	.275	.023	.022	.021	.023
			Roots	.9591	.4795	20.93		.560		.185		.020	
4	.16	.18	Tops	1.2293		17.85		.169		.035		.036	
				1.2134	1.2213	16.75	17.30	.131	.150	.049	.042	.....	.036
			Roots	.5444	.2722	16.47		.690		.101		.024	
5	.20	.18	Tops	1.1786		21.67		.333		.039		.033	
				1.1021	1.1403	21.07	21.37	.256	.294	.044	.041	.....	.033
			Roots	1.0500	.5250	25.40		.820		.299		.028	
6	.24	.18	Tops	.9773		21.47		.448		.462		.045	
				.9923	.9848	21.65	21.56	.545	.496	.486	.470	.033	.039
			Roots	.8600	.4300	26.07		1.290		.407		.024	
7	.28	.18	Tops	.8459		18.62		.476		.437		.032	
				.7450	.7954	20.05	19.33	.523	.499	.409	.420	.037	.035
			Roots	.6014	.3007	24.87		1.580		.565		.023	
8	.32	.18	Tops	.4608		21.43		.640		1.05		.027	
				.5316	.4962	.....	21.43	.568	.604	1.24	1.14	.019	.023
			Roots	.3350	.1675	29.00		3.330		1.07		.026	
9	.36	.18	Tops	.1916		18.56		.747		1.43		.048	
				.2349	.2132	18.80	18.68	.955	.851	1.59	1.50	.049	.047
			Roots	.0976	.0488	18.05		1.000		2.80			
				.2269	.1819	13.60	13.50	.235	.370	1.71	1.71	.031	.053
10		.18	Tops	.1369		13.40		.505		2.03		.016	
			Roots	.0614	.0307	16.62		.112		3.68			

Grown January 24–March 6, 1916.

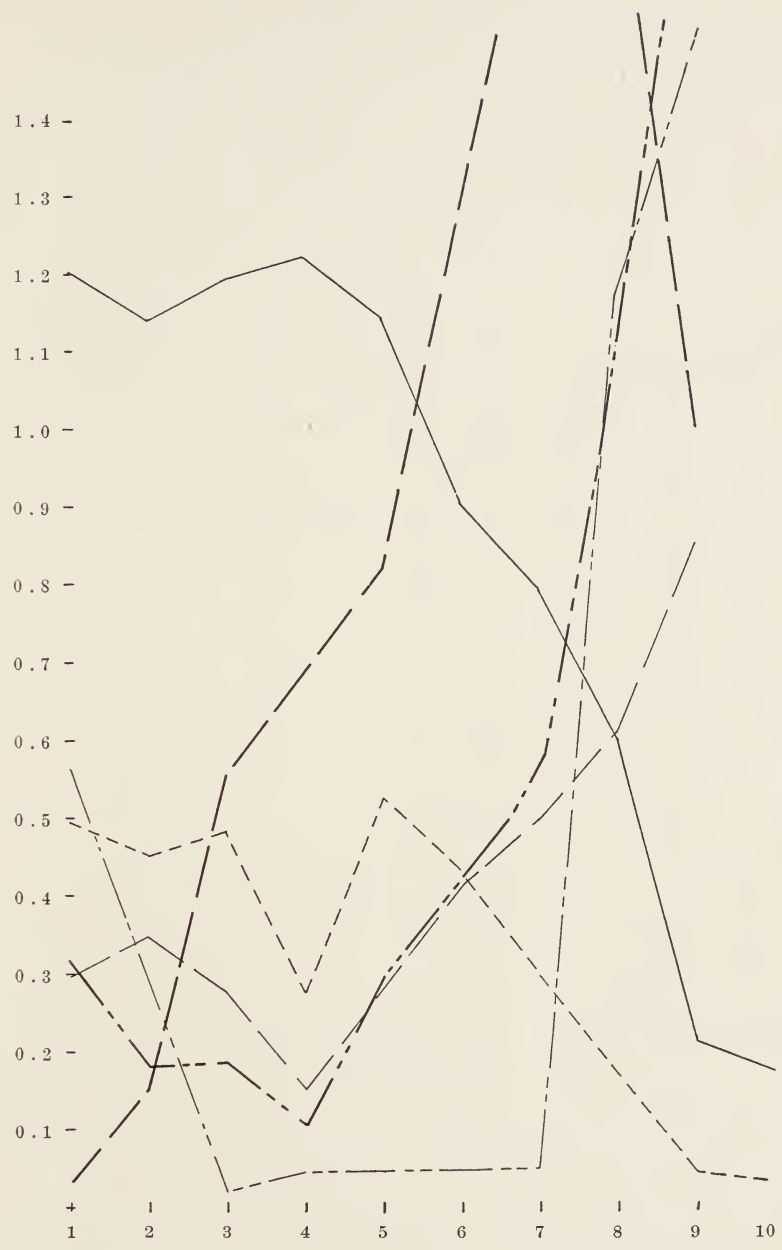

Fig. 6
Magnesium Sulphate + Calcium Chloride
(See Table 6)

TABLE 7

Potassium Chloride

No.	Solution $Ca(NO_3)_2$	Solution $MgSO_4$		Dry Weight	Mean	Percentage of Ash	Mean	Percentage of Ca	Mean	Percentage of Mg	Mean	Percentage of Fe	Mean
1	.04	.15	Tops	1.8850		17.90		.067		.967		.026	
				1.1941	1.5395	20.00	18.95	.067	.067	.808	.887	.018	.022
			Roots	.9776	.4588	19.35		.062		.101		.093	
2	.08	.15	Tops	1.7825		16.20		.101		.762		.024	
				1.5648	1.6731	16.92	16.56	.120	.110	.842	.802	.021	.023
			Roots	.8813	.4406	25.37		.135		.430		.012	
3	.12	.15	Tops	1.6850		19.90		.487		2.190			
				.....	.8425	.....	19.90	.....	.487		2.190		
			Roots	.6284	.3141	31.20		.037		2.390			
4	.16	.15	Tops	1.2078		16.67		.247		2.120			
				.....	.6030	.....	16.67	.....	.247	.....	2.120		
			Roots	.5668	.2834	27.80		.037		2.410			
5	.20	.15	Tops	.....									
			Roots	.....	No growth								
6	.24	.15	Tops	.5818		18.50		.550		9.20			
				.....	.2909	.....	18.50	.....	.550	.....	9.200		
			Roots	.1581	.0740	21.90		.195		6.520			
7	.28	.15	Tops	.....									
			Roots	.....	No growth								
8	Full Nutrient		Tops	1.5682		18.33		.293		.231			
				1.5775	1.5728	19.40	18.86	.312	.302	.279	.255		
			Roots	.9776		20.40		.271		.279			

Amounts too small to determine.

Grown April 14–May 27, 1916.

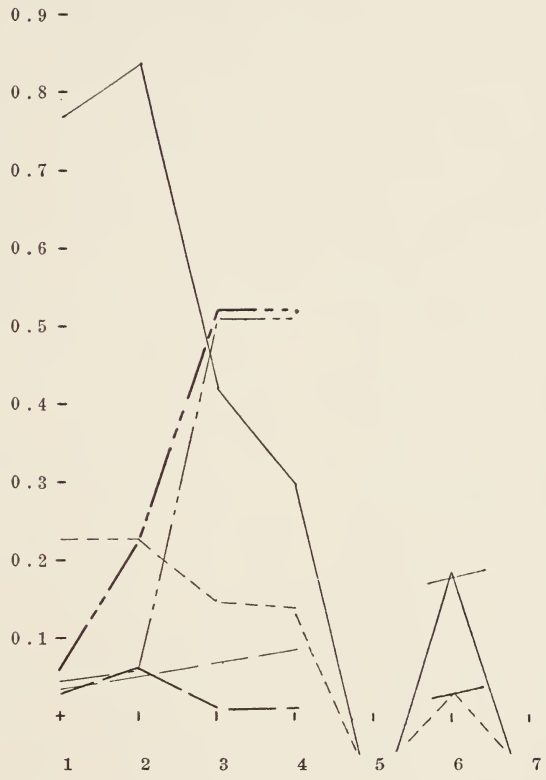

Fig. 7
Magnesium Sulphate + Calcium Nitrate
(See Table 7)

TABLE 8

Magnesium Sulphate + Calcium Nitrate

No.	Solution KCl	Dry Weight		Mean	Percentage of Ash	Mean	Percentage of Ca	Mean	Percentage of Mg	Mean	Percentage of Fe	Mean	Percentage of K	Mean
1	.04	Tops	1.1563		19.65		.078		.228		.028		1.37	
			1.1128	1.1345	19.65	19.65	.....		.201	.214	.045	.037	1.80	1.58
		Roots	.5038	.2519	17.07		.256		.175		.173		.61	
2	.06	Tops	1.0773		24.00		.128		.083		.041		3.54	
			1.0791	1.0782	25.90	24.95	.113	.120	.118	.100	.030	.036	3.54	3.54
		Roots	.5979	.2989	16.27		.241		.170		.....		.....	
3	.08	Tops	.7638		27.50		.302		.201		.064		4.81	4.56
		Roots	.4659	.1829	17.20		.238		.180		.106		4.80	
4	.10	Tops	.8417		25.90		.204		.302		.268		3.56	
			.7900	.8158	24.40	25.15	.186	.195	.205	.253	.280	.274	3.80	3.68
		Roots	.3135	.1567	14.20		.570		.300		.072		1.02	
5	.12	Tops	.5656		31.00		.283		.378		.195		4.78	
			.5815	.5734	29.80	30.40	.265	.274	.657	.567	.072	.133	4.30	4.54
		Roots	.2215	.1107	18.00		.780		.101		.175		1.67	
6	.14	Tops	.4825		39.50		.217		.478		.091		9.11	
			.4200	.4531	32.30	35.90	.222	.219	.454	.466	.092	.091	7.10	8.10
		Roots	.1762		20.83		.617		.139		.021		1.53	
7	.16	Tops	.5375		42.00		.248		.730		.071		.....	
			.....	.2687	.....	42.00	.....	.248	.....	.730	.....	.071	11.21	11.21
		Roots	.1339	.0669	23.83		.505		1.34		.250		2.31	

Grown January 31–March 13, 1916.

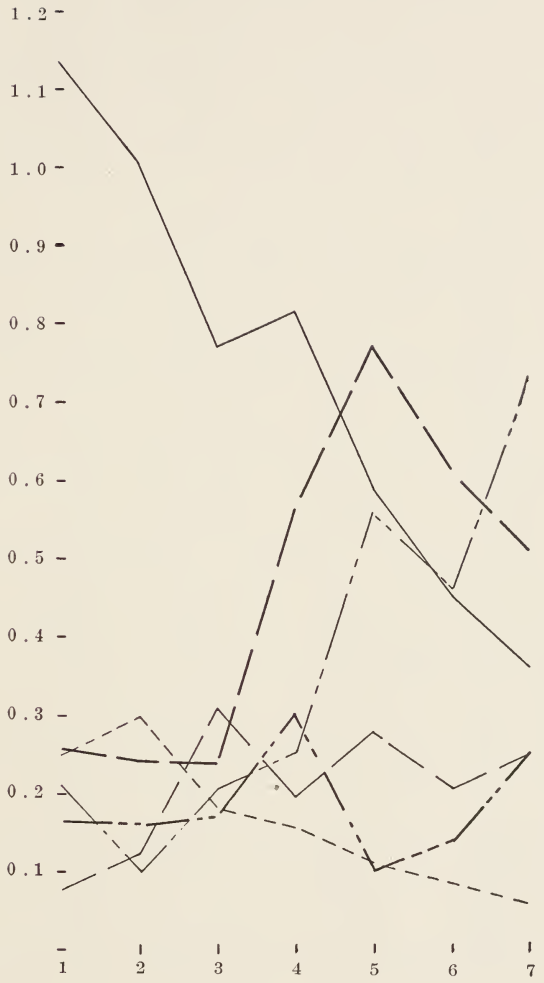

Fig. 8
Potassium Chloride
(See Table 8)

TABLE 9

Magnesium Sulphate + Potassium Chloride

No.	Solution $MgSO_4$	Solution KCl	Dry Weight		Mean	Percentage of Ash	Mean	Percentage of Ca	Mean	Percentage of Mg	Mean	Percentage of Fe	Percentage of K	Mean
1	.04	.18	Tops	.6579		19.65		.141		.490			2.13	
				.6379	.6479	21.20	20.42	.162	.151	.500	.495		1.72	1.92
			Roots	.2800	.1400	20.00		.....		2.79			.67	
2	.08	.18	Tops	.6800		22.07		.138		.430			3.21	
				.7162	.6981	25.10	23.58	.171	.154	.480	.455		3.00	3.10
			Roots	.2682	.1341	23.50		.590		1.350			.72	
3	.12	.18	Tops	.4957		22.60		.292		.....			3.78	
				.5202	.5079	26.50	24.55	.310	.301	.923	.923		3.82	3.80
			Roots	.2200	.1100	25.25		.745		.104			.86	
4	.16	.18	Tops	.6229		23.50		.152		.382			4.12	
				.6464	.6346	24.70	24.10	.169	.161	.381	.381		4.21	4.16
			Roots	.3123	.1561	22.70		.291		.561			1.40	
5	.20	.18	Tops	.3643		26.20		.440		.977			5.01	
				.4819	.4231	.....	26.20	.....	.440	.....	.977		.....	5.01
			Roots	.2063	.1031	24.00		.678		1.060			2.20	
6	.24	.18	Tops	.3259		33.20		.407		1.040			7.22	
				.2141	.2700	37.60	35.40	.423	.415	2.920	1.970		8.13	7.66
			Roots	.1297	.0648	22.10		.750		1.490			2.80	
7	.28	.18	Tops	.1522		31.10		.299		1.030			9.20	
				.2050	.1786	35.10	33.10	.265	.282	.990	1.010		11.30	10.25
			Roots	.0913	.0456	24.10		.735		2.900			3.10	
8	.32	.18	Tops	.2704		36.10		.263		.890			11.20	
				.2997	.2850	36.20	36.15	.211	.237	.810	.850		7.20	9.20
			Roots	.1467	.0733	22.57		.229		.818			2.17	
9	.36	.18	Tops	.2800		23.90		.261		.801			3.21	
				.2846	.2823	25.00	24.45	.278	.269	.895	.848		4.17	3.64
			Roots	.1417	.0708	21.60		.699		.248			2.18	
Full Nutrient			Tops	1.0992		20.17		.310		.268				
				1.0750	1.0872	19.12	18.69	.297	.303	.228	.224			
			Roots	.8120		20.00		.271		.233				

Amounts too small to determine.

Grown January 31–March 13, 1916.

Fig. 9
Magnesium Sulphate + Potassium Chloride
(See Table 9)

TABLE 10

Aluminum Chloride

No.	Solution $AlCl_3$	Dry Weight		Mean	Percentage of Ash	Mean	Percentage of Ca	Mean	Percentage of Mg	Mean	Percentage of Fe	Mean
1	.0000033	Tops	.4438		22.42		.098		.450		.075	
			.4688	.4563	20.40	21.40	.092	.095	.590	.520	.077	.076
		Roots	.4315	.2157	20.20		.055		.590		.089	
2	.0000165	Tops	.2934		23.20		.196		.793		.151	
			.2745	.2839	22.70	22.95	.180	.188	.793	.793	.140	.145
		Roots	.1976	.0988	18.70		.250		.990		.061	
3	.000033	Tops	.2872		21.09		.316		.953		.173	
			.3595	.3233	22.60	21.84	.321	.318	1.000	.970	.154	.163
		Roots	.2964	.1482	19.55		.153		.504		.130	
4	.000066	Tops	.3028		21.09		.342		.605		.128	
			.3200	.3114	22.80	21.94	.334	.338	.615	.610	.155	.141
		Roots	.2422	.1211	19.55		.334		.840		.171	
5	.000132	Tops	.2720		22.60		.423		.835		.101	
			.2479	.2599	19.00	20.80	.450	.436	.837	.836	.134	.117
		Roots	.2645	.1322	26.60		.382		1.110		.104	
6	.000331	Tops	.3178		20.20		.246		1.130		.137	
			.4016	.3597	21.90	21.05	.247	.246	.690	.91	.124	.130
		Roots	.2550	.1275	27.90		.108		.....		.108	
7	.00331	Tops	.3863		22.30		.258		.535		.114	
			.2369	.3116	21.82	22.60	.268	.263	1.230	.88	.187	.150
		Roots	.2153	.1076	29.40		.583		.330		.231	

Grown August 26–October 7, 1916.

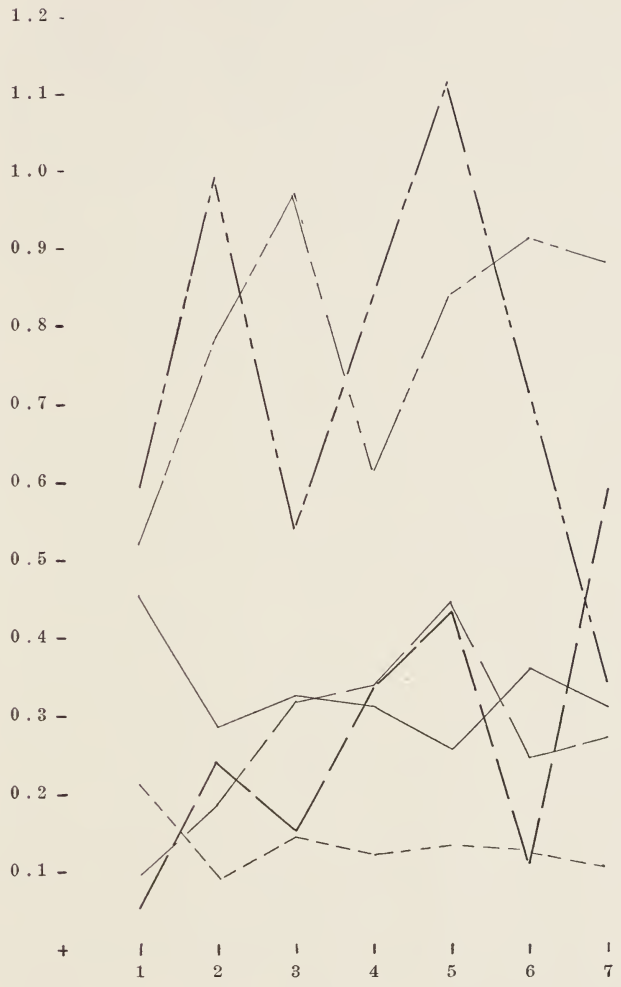

Fig. 10
Aluminum Chloride
(See Table 10)

TABLE 11

Calcium Chloride + Aluminum Chloride

No.	Solution $AlCl_3$	Solution $CaCl_2$	Dry Weight		Mean	Percentage of Ash	Mean	Percentage of Ca	Mean	Percentage of Mg	Mean	Percentage of Fe	Mean
1	.0000033	.20	Tops	.2962		24.20		1.630		.745		.....	
				.2087	.2524	23.10	23.65	1.820	1.72	.830	.787	.....	
			Roots	.1897	.0948	20.40		.730		.872		.....	
2	.0000165	.20	Tops	.2542		24.23		1.610		.890		.123	
				.2678	.2610	22.18	23.20	1.720	1.66	9.30	.910	.313	.21
			Roots	.2745	.1372	26.17		.731		.....		.....	
3	.0000331	.20	Tops	.3324		23.00		1.250		.787		.503	
				.3706	.3515	25.20	24.10	1.460	1.35	.903	.845	.540	.52
			Roots	.2942	.1471	26.10		.790		.817		.075	
4	.0000662	.20	Tops	.2139		23.20		1.210		.821		.237	
				.2337	.2238	21.70	22.45	1.030	1.12	.733	.772	.114	.17
			Roots	.1839	.0919	24.20		.621		1.02		.....	
5	.000132	.20	Tops	.2148		20.58		1.400		.932		.248	.18
				.3085	.2611	24.10	22.34	1.060	1.23	.897	.913	.119	.18
			Roots	.2239	.1119	20.20		.513		.947		.....	
6	.000331	.20	Tops	.2337		24.10		1.420		.632		.105	
				.2137	.2237	21.32	22.71	1.270	1.34	.711	.621	.210	.15
			Roots	.1682	.0841	20.16		.672		1.310		.....	
7	00331	.20	Tops	.2496		24.10		1.330		.490		.155	
				.1946	.2221	22.90	23.50	1.550	1.44	.516	.503	.285	.22
			Roots	.1296	.0648	26.40		.780		.253		.021	
Full Nutrient			Tops	.7103		18.17		.322		.221			
				.7327	.7215	19.31	18.74	.377	.349	.270	.245		
			Roots	.6600	.3300	19.99		.300		.233			

Grown August 26–October 7, 1916

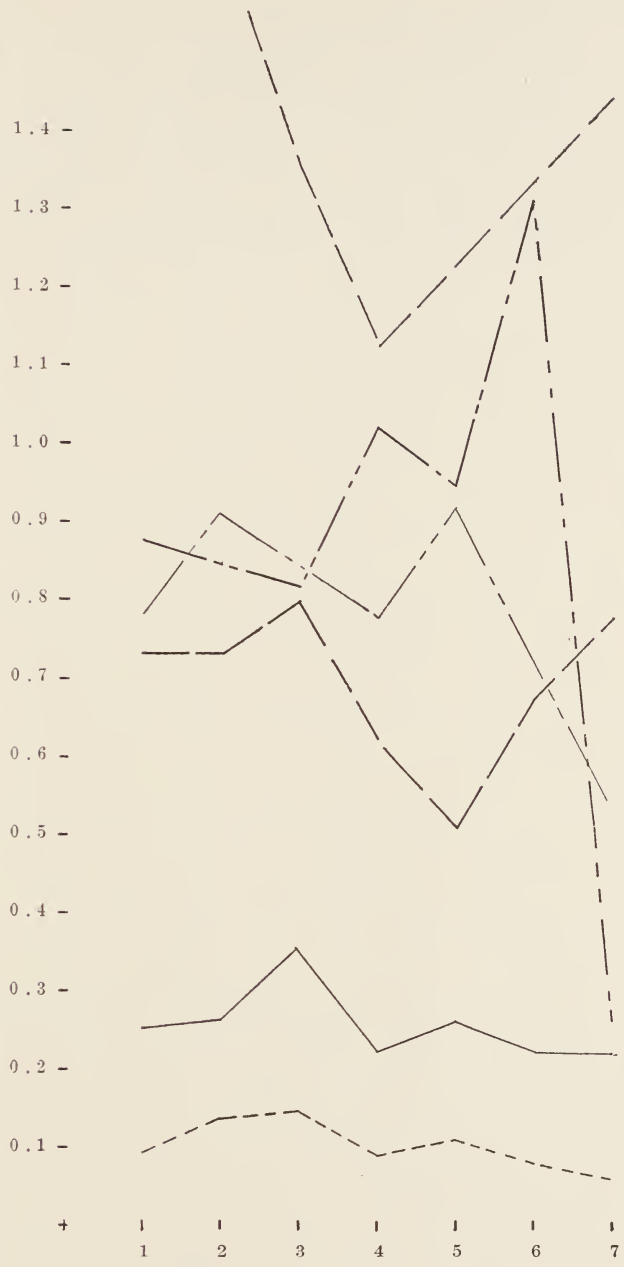

Fig. 11
Calcium Chloride + Aluminum Chloride
(See Table 11)

TABLE 12

Aluminum Chloride + Magnesium Chloride

No.	Solution $AlCl_3$	Solution $MgCl_2$	Dry Weight		Mean	Percentage of Ash	Mean	Percentage of Ca	Mean	Percentage of Mg	Mean	Percentage of Fe	Mean
1	.0000033	.20	Tops	.2819		19.02		.426		2.13		.121	
				.5457	.4138	18.71	18.86	.371	.398	1.91	2.02	.131	.126
			Roots	.2936	.1468	21.31		.321		2.12		.122	
2	.0000165	.20	Tops	.3539		17.31		.327		1.71		.141	
				.3000	.3269	19.21	18.16	.421	.374	1.83	1.77	.132	.136
			Roots	.1750	.0875	22.17		.400		1.71		.101	
3	.0000331	.20	Tops	.2243		21.05		.352		2.51		.148	
				.2259	.2251	17.70	19.39	.448	.400	2.80	2.65	.147	.147
			Roots	.1239	.0614	24.10		.366		1.96		.135	
4	.0000662	.20	Tops	.6327		19.00		.147		1.46		.050	
				.7644	.6985	18.10	18.55	.130	.138	1.36	1.42	.047	.049
			Roots	.5526	.2763	19.95		.111		.333		.040	
5	.000132	.20	Tops	.2406		19.75		.280		2.78		.069	
				.3156	.2781	19.55	19.65	.282	.281	3.11	2.94	.064	.066
			Roots	.1250	.0625	24.00		.186		5.88		.181	
6	.000331	.20	Tops	.2279		16.50		.407		.940		.091	
				.2048	.2163	19.90	18.20	.467	.437	.557	.74	.081	.086
			Roots	.1700	.0850	22.76		.302		2.51		.098	
7	.00331	.20	Tops	.2400		17.40		.131		2.14		.161	
				.1450	.1925	18.80	18.10	.161	.145	1.71	1.92	.192	.176
			Roots	.0990	.0495	32.60		.200		4.53		.439	

Grown August 26–October 7, 1916.

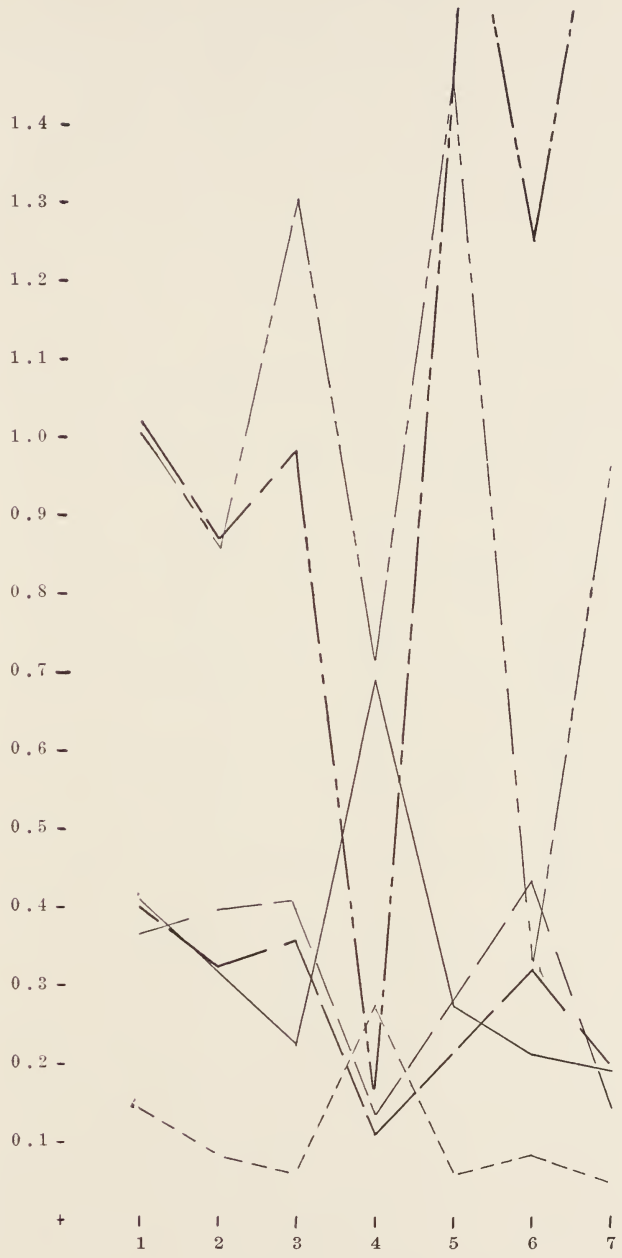

Fig. 12
Aluminum Chloride + Magnesium Chloride
(See Table 12)

TABLE 13

Ferric Chloride

No.	Solution $FeCl_3$	Dry Weight		Mean	Percentage of Ash	Mean	Percentage of Ca	Mean	Percentage of Mg	Mean	Percentage of Fe	Mean
1	.000089	Tops	.7712		14.50		.199		.258		.214	
			.8376	.8044	19.20	16.85	.228	.213	.237	.247	.199	.206
		Roots	.7143	.3571								
2	.000168	Tops	.7884		17.90		.138		.244		.200	
			1.2762	1.0323	19.30	16.60	.106	.122	.299	.271	.197	.198
		Roots	.6462	.3231	17.60		.178		.250		.220	
3	.00168	Tops	1.3519		15.70		.045		.259		.247	
			1.1269	1.2394	18.10	16.90	.046	.045	.225	.242	.232	.239
		Roots	.9034	.4517	17.10		.054		.213		.....	
4	.0168	Tops	1.0000		16.78		.033		.254		.109	
			1.2750	1.1370	16.51	16.64	.028	.030	.222	.238	.138	.123
		Roots	.7219	.3609	20.98		.068		.203		.231	
Full Nutrient		Tops	1.0992		20.17		.310		.268			
			1.0750	1.0872	19.12	18.69	.297	.303	.228	.224		
		Roots	.8120		20.00		.271		.233			

Grown January 24–March 6, 1916.

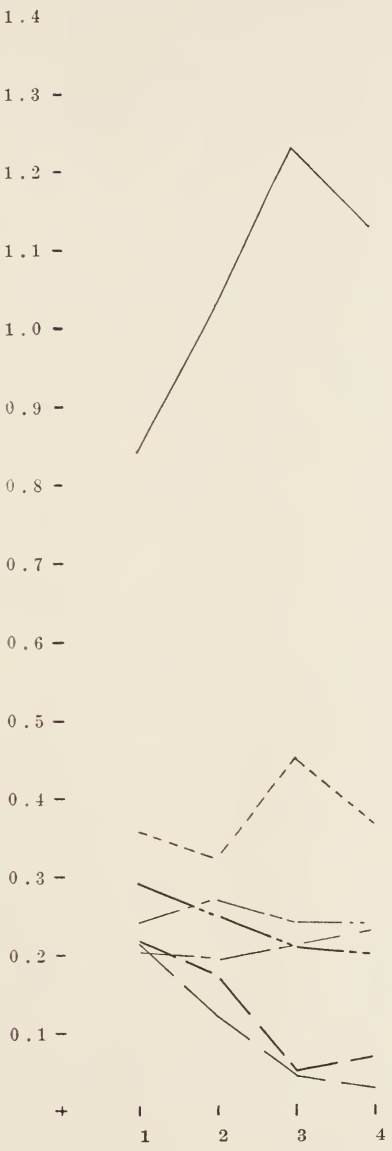

Fig. 13
Ferric Chloride
(See Table 13)

TABLE 14

Ferric chloride + Calcium Chloride

No.	Solution $FeCl_3$	Solution $CaCl_2$		Dry Weight	Mean	Percentage of Ash	Mean	Percentage of Ca	Mean	Percentage of Mg	Mean	Percentage of Fe	Mean
1	.000089	.20	Tops	.4826		18.27		1.02		.164		.....	
				.4116	.4471	18.50	18.38	1.83	1.42	.137	.150	.....	
			Roots	.4143	.2071	28.35		.531		.222		.100	
2	.000168	.20	Tops	.5238		17.72		1.77		.194		.080	
				.5847	.5592	16.04	16.88	1.01	1.39	.101	.147	.090	.085
			Roots	.6115	.3057	22.70		.188		.229		.03	
3	.000352	.20	Tops	.2732		20.42		2.78		.256		.370	
				.3204	.2918	20.61	20.51	3.28	3.03	.255	.255	.400	.38
			Roots	.1774	.0887	22.40		1.76		.692		.120	
4	.000712	.20	Tops	.5910		19.01		2.85		.212		.50	
				.3810	.4860	.....	19.01	2.15	2.00	.262	.237	.40	.45
			Roots	.5053	.2526	31.30		1.06		.026		.02	
5	.00142	.20	Tops	.5427		16.56		1.06		.064		.36	
				.6353	.5890	17.79	17.17	1.33	1.19	.051	.058	.50	.43
			Roots	.6238	.3119	29.50		.350		.010		.16	
6	.00356	.20	Tops	.2715		14.76		1.32		.097		1.18	
				.2632	.2673	17.09	15.92	1.23	1.27	.133	.115	1.02	1.10
			Roots	.2196	.1098	20.03		1.13		.018		.98	
7	.0058	.20	Tops	.1792		20.03		2.37		.256		.800	
				.2514	.2153	20.92	20.47	2.08	2.22	.297	.276	.900	.85
			Roots	.0636	.0318	29.30		1.68		.020		.200	
8	.0168	.20	Tops	.3293		17.03		.584		.246		.148	
				.4393	.3843	19.08	18.05	.460	.522	.175	.210	.120	.134
			Roots	.3565	.1783	28.04		.505		.049		.06	

Grown December 9–January 19, 1916.

Iron determined colorimetrically in this series.

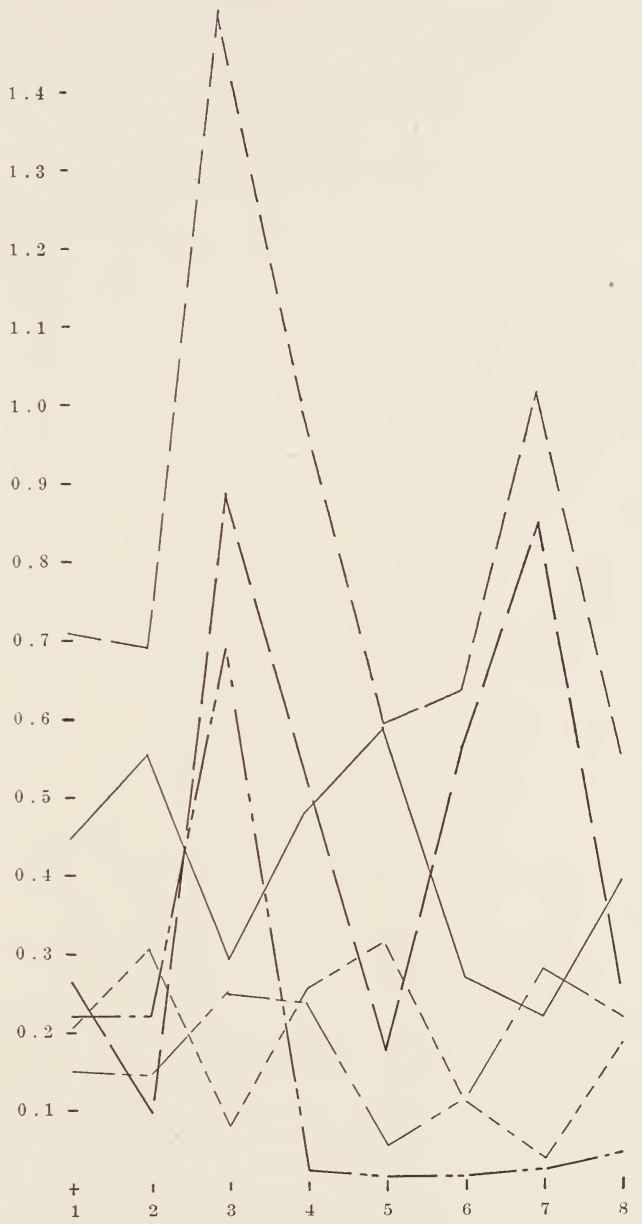

Fig. 14
Ferric Chloride + Calcium Chloride
(See Table 14)

TABLE 15

Ferric Chloride + Magnesium Chloride

No.	Solution $FeCl_3$	Solution $MgCl_2$		Dry Weight	Mean	Percentage of Ash	Mean	Percentage of Ca	Mean	Percentage of Mg	Mean	Percentage of Fe	Mean
1	.000089	.20	Tops	.9650		18.48		.182		.874		.091	
				.7444	.8547	18.70	19.59	.163	.172	.833	.853	.111	.101
			Roots	.6126	.3063	25.05		.204		.547		.047	
2	.000168	.20	Tops	.7875		18.12		.181		.189		.210	
				.9525	.8700	18.67	18.44	.164	.172	.191	.190	.....	.210
			Roots	.6816	.3408	21.40		.229		.553		.033	
3	.000352	.20	Tops	.8787		15.17		.172		.218		.067	
				.7365	.8076	17.15	16.16	.137	.154	.310	.264	.073	.070
			Roots	.6525	.3262	22.95		.176		.515		.....	
4	.000712	.20	Tops	1.0414		16.77		.324		.116		.093	
				1.1515	1.1464	17.57	17.17	.311	.317	.119	.117	.094	.093
			Roots	.4837	.2418	21.86		.258		.503		.057	
5	.00142	.20	Tops	.6648		17.40		.209		.069		.233	
				.7927	.7287	16.22	16.81	.185	.197	.103	.086	.209	.221
			Roots	.4627	.2313	22.12		.258		.093		.058	
6	.00356	.20	Tops	1.1639		16.50		.176		.153		.147	
				.9476	1.0557	16.10	16.30	.109	.142	.....	.153	.128	.137
			Roots	.3298	.1649	20.28		.433		.936		.066	
7	.0058	.20	Tops	.6608		17.08		.340		.218		.040	
				.6189	.7398	16.07	16.57	.400	.370	.234	.226	.....	.040
			Roots	.4846	.2423	20.09		.235		.788		.050	
8	.0168	.20	Tops	1.0927		18.96		.344		1.020		.140	
				1.0824	1.0875	20.05	19.45	.391	.367	1.100	1.06	.120	.130
			Roots	.6358	.3179	21.05		.177		.262		.051	

Grown January 24–March 6, 1916.

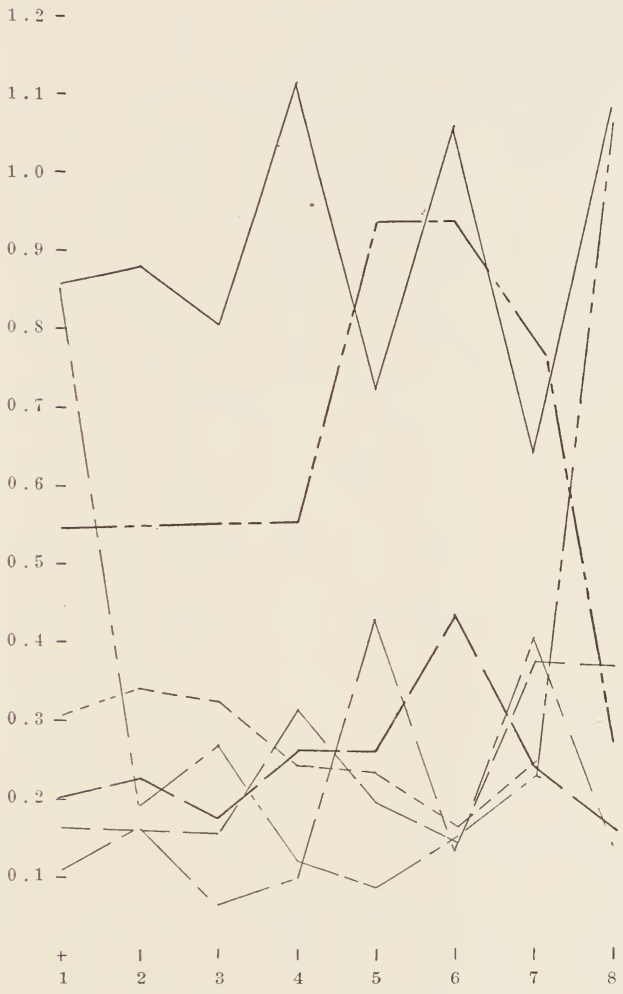

Fig. 15
Ferric Chloride + Magnesium Chloride
(See Table 15)

TABLE 16

Copper Chloride

No.	Solution $CuCl_2$	Drv Weight		Mean	Percentage of Ash	Mean	Percentage of Ca	Mean	Percentage of Mg	Mean	Percentage of Fe	Mean	Percentage of Cu	Mean
1	.000038	Tops	.4611		25.60		.425		.194		.120		.....	
		Roots	.4692	.4651	23.60	24.60	.420	.412	.191	.192	.201	.160	.....	
2	.000079	Tops	.2492		20.20		.455		.716		.155		.....	
		Roots	.3242	.2867	24.12	22.16	.563	.509	.723	.719	.221	.188	.....	
3	.00015	Tops	.3887		24.50		.312		1.10		.114		.....	
		Roots	.4198	.4042	25.30	24.90	.361	.336	.90	1.00	.0261	.070	.....	
4	.00031	Tops	.2744		18.45		.150		1.43		.040		.001	
		Roots		.1372		18.45		.150		1.48		.040		
5	.00047	Tops	.2581		22.00		.176		1.35		.214		.002	
		Roots	.2344	.2462	18.10	20.05	.102	.139	1.02	1.18	.094	.154	.002	.002
6	.00063	Tops	.0785		19.10		.254		3.77		.....		.003	
		Roots	.0700	.0742	18.21	18.65	.425	.339	5.10	4.43	.248	.248	.005	.004
7	.00079	Tops	.....											
		Roots	.....		No growth.									
8	.00198	Tops	.....											
		Roots	.....		No growth.									
9	.00392	Tops	.....											
		Roots	.....		No growth.									
Full Nutrient		Tops	1.1234		19.20		.311		.213					
			1.0268	1.0751	21.00	20.10	.241	.276	.199	.206				
		Roots	.7210		18.99		.299		.216					

Grown March 9–April 20, 1916.

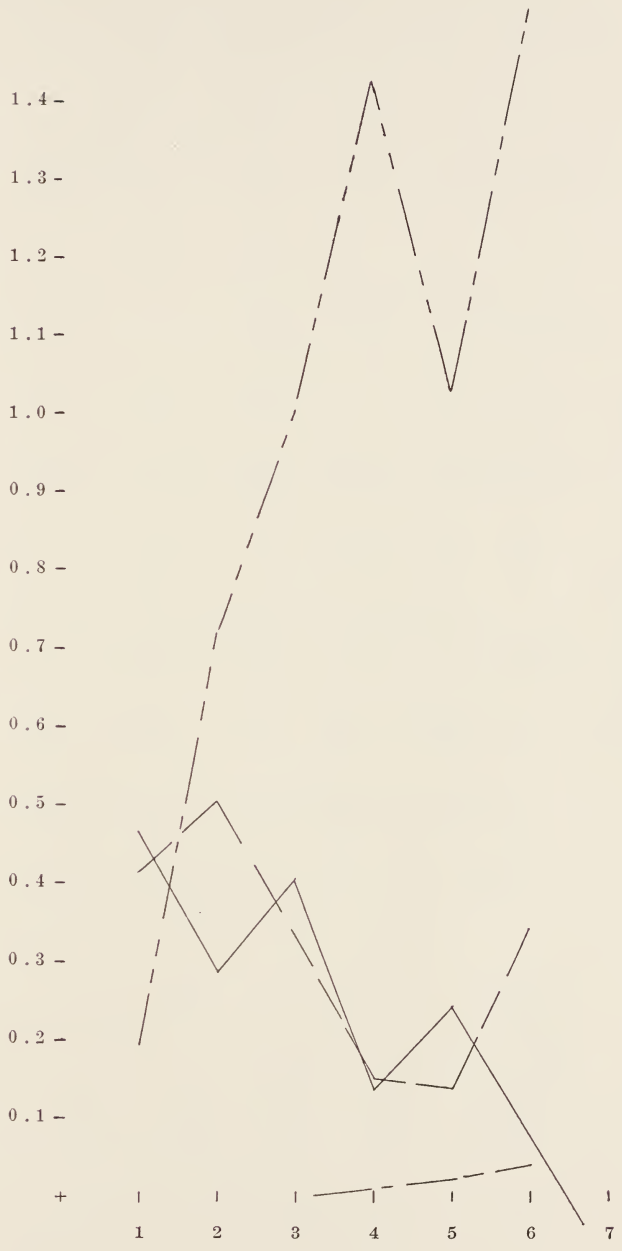

Fig. 16
Copper Chloride
(See Table 16)

TABLE 17

Copper Chloride + Ferric Chloride

No.	Solution $CuCl_2$	Solution $FeCl_3$		Dry Weight	Mean	Percentage of Ash	Mean	Percentage of Ca	Mean	Percentage of Mg	Mean	Percentage of Fe	Mean	Percentage of Cu	Mean
1	.0000094	.0000087	Tops	.4661		20.52		.0163		.126		.059		.....	
				.4826	.4743	19.00	18.76	.0122	.014	1.550	1.41	.039	.049	.....	
			Roots	.5597	.2988	17.95		.131		.336		.059		.002	
2	.0000283	.0000263	Tops	1.1519		20.30		.197		.321		.038		.....	
				.9700	1.0609	18.10	19.20	.190	.193	3.610	.341	.039	.038	.....	
			Roots	.9855	.4927	18.90		.070		.180		.056		.002	
3	.0000472	.000042	Tops	.5505		22.49		.259		1.11		.070		.....	
				.5600	.5552	20.60	21.54	.259	.259	1.26	1.18	.068	.069	.....	
			Roots	.2981	.1490	20.20		.252		.71		.056		.003	
4	.000067	.000058	Tops	.4759		21.50		.375		1.13		.058		.001	
				.4945	.4852	19.85	20.67	.295	.335	1.05	1.09	.044	.051	.001	.001
			Roots	.1331	.0665	12.70		1.250		1.54		.023		.007	
5	.000094	.00082	Tops	.4750		21.40		.258		.860		.090		.....	
				.3550	.4150	18.20	19.80	.269	.268	.790	.82	.070	.080	.....	
			Roots	.1850	.0525	11.20		.560		.68		.016		.009	

Grown April 14–May 27, 1916.

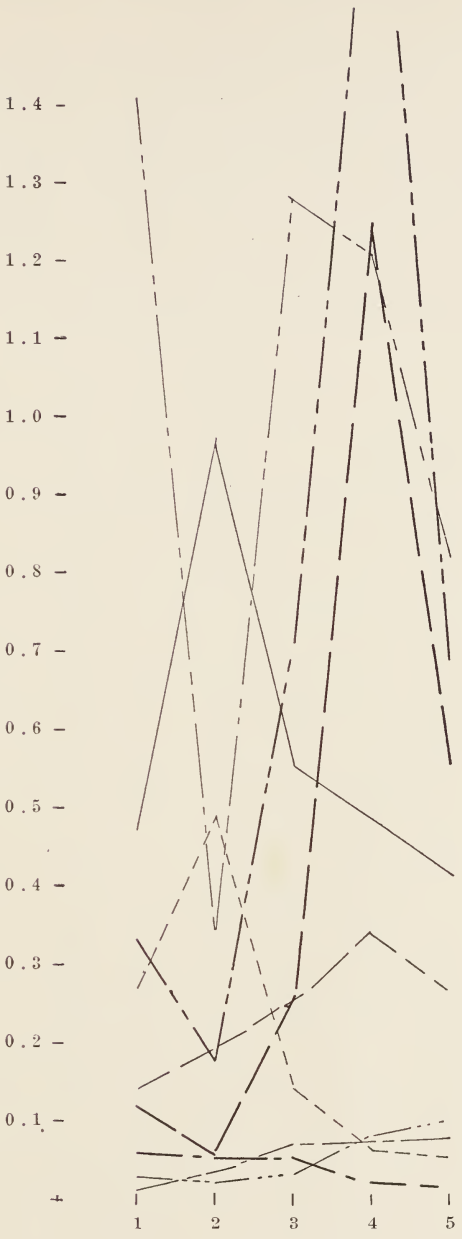

Fig. 17
Copper Chloride + Ferric Chloride
(See Table 17)

TABLE 18

Mercuric Chloride + Copper Chloride

No.	Solution $HgCl_2$	Solution $CuCl_2$	Dry Weight		Mean	Percentage of Ash	Mean	Percentage of Ca	Mean	Percentage of Mg	Mean	Percentage of Fe
1	.0000047	.0000023	Tops	.1175		20.15		.674		1.21		
				.1608	.1392	21.20	20.67	.517	.595	.935	1.07	
			Roots	.0869	.0434	18.65		1.220		.276		
2	.0000094	.0000047	Tops	.1792		20.00		.531		.873		
				.2675	.2233	20.32	20.16	.612	.572	.942	.907	
			Roots	.0846	.0423	16.71		1.410		.291		
3	.0000184	.0000094	Tops	.3778		24.70		.493		.488		
				.3328	.3503	23.30	24.30	.570	.531	.....	.488	
			Roots	.0928	.0467	15.45		1.360		.211		
4	.000047	.000023	Tops	.3600		21.22		.431		.834		
				.2334	.2967	23.20	22.21	.521	.471	.921	.877	
			Roots	.1109	.0554	17.32		.....		.361		
5	.000094	.000047	Tops	.3643		22.00		.359		.737		
				.4372	.4007	20.12	21.06	.354	.356	.695	.716	
			Roots	.1109	.0554	17.32		.....		.361		
6	.000189	.000094	Tops	.2385		22.30		.521		.921		
				.3105	.2745	24.71	23.50	.503	.512	.973	.947	
			Roots	.1146	.0573	12.71		1.340		.333		
7	.000378	.000188	Tops	.1500		21.60		.573		1.212		
				.2150	.1825	23.40	22.50	.672	.622	1.071	1.14	
			Roots	.0609	.0304	12.82		.....		.412		

Too small amounts to determine.

Grown January 24–March 6, 1916.

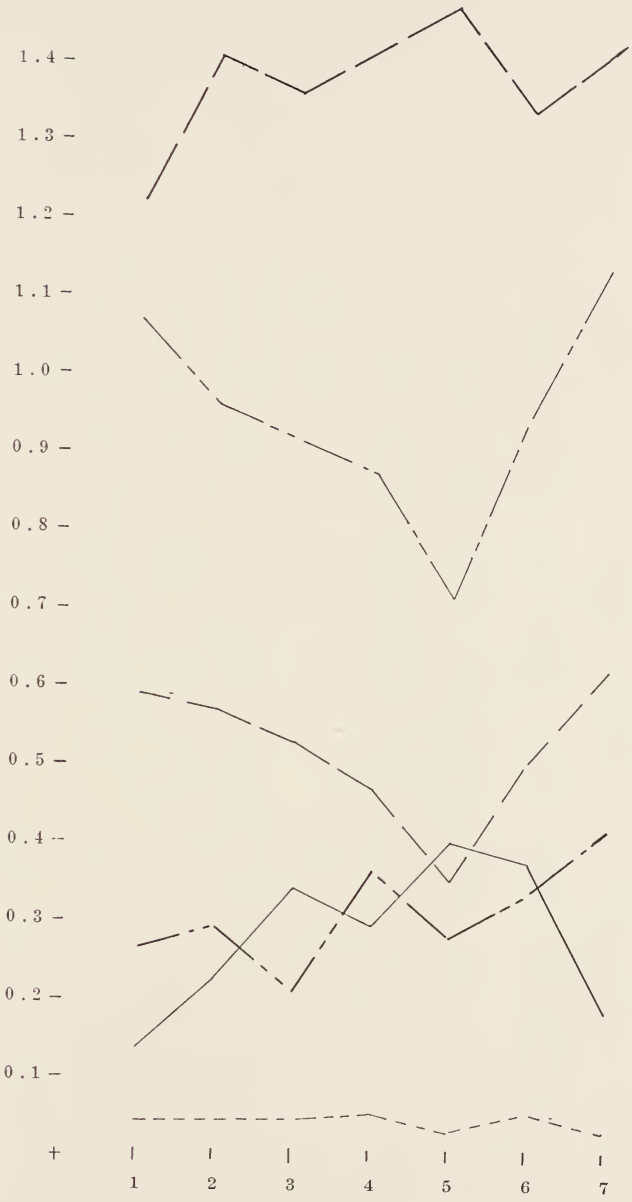

Fig. 18
Mercuric Chloride
(See Table 18)

TABLE 19

Copper Sulphate

No.	Solution $CuSO_4$	Dry Weight		Mean	Percentage of Ash	Mean	Percentage of Ca	Mean	Percentage of Mg	Mean	Percentage of Fe	Mean	Percentage of Cu
1	.0000048	Tops	.6148		22.80		.104		.331		.081		.....
			.7726	.6937	21.71	22.25	.117	.110	.520	.425	.071	.076	.....
		Roots	.4406	.2203	20.61		.153		.548		.088		.005
2	.0000094	Tops	.5394		21.42		.066		.415		.092		.....
			.8462	.6928	17.50	17.46	.056	.061	.477	.446	.058	.075	.....
		Roots	.4512	.2256	16.40				1.010		.073		.005
3	.0000188	Tops	.4712		24.40		.177		.633		.093		.....
			.3128	.3920	18.90	21.65	.234	.205	.743	.688	.070	.082	.....
		Roots	.2948	.1474	22.50				1.170		.056		.001
4	.0000378	Tops	1.5098		22.02		.021		.210		.....		.....
			1.0836	1.2967	18.90	20.46	.018	.020	2.09	2.09	.025	.025	.....
		Roots	.9436	.4718	18.85		.083		.215		.065		.003
5	.0000567	Tops	.7544		21.18		.105		.321		.036		.....
			.8022	.7783	20.44	20.81	.106	.105	.376	.348	.048	.042	.....
		Roots	.5265	.2632	18.10		.128		.317		.010		.004
6	.0000755	Tops	.7598		21.60		.156		.470		.058		.....
			.6632	.7125	20.83	21.41	.147	.151	.396	.433	.050	.054	.....
		Roots	.5889	.2944	19.71		.101		.377		.084		.004
7	.0000945	Tops	.3339		23.21		.374		.643		.011		.....
			.2439	.2889	23.60	23.45	.294	.334	.800	.721	.015	.013	.....
		Roots	.1567	.0783	18.00		.982		2.08		.....		.002
8	.000189	Tops	.3267		22.61		.673		.630		.....		.....
			.3786	.3526	24.80	23.70	.480	.576	.947	.788	.....	.....	.....
		Roots	.1630	.0815	21.40		1.430		1.450		.....		.002
9	.000378	Tops	.2695		24.22		.530		1.31		.....		.....
			.2372	.2533	22.00	23.11	.407	.469	1.34	1.32	.....	.....	.....
		Roots	.0696	.0348	23.80		1.53		.....		.....		.008

Grown April 14–May 27, 1916.

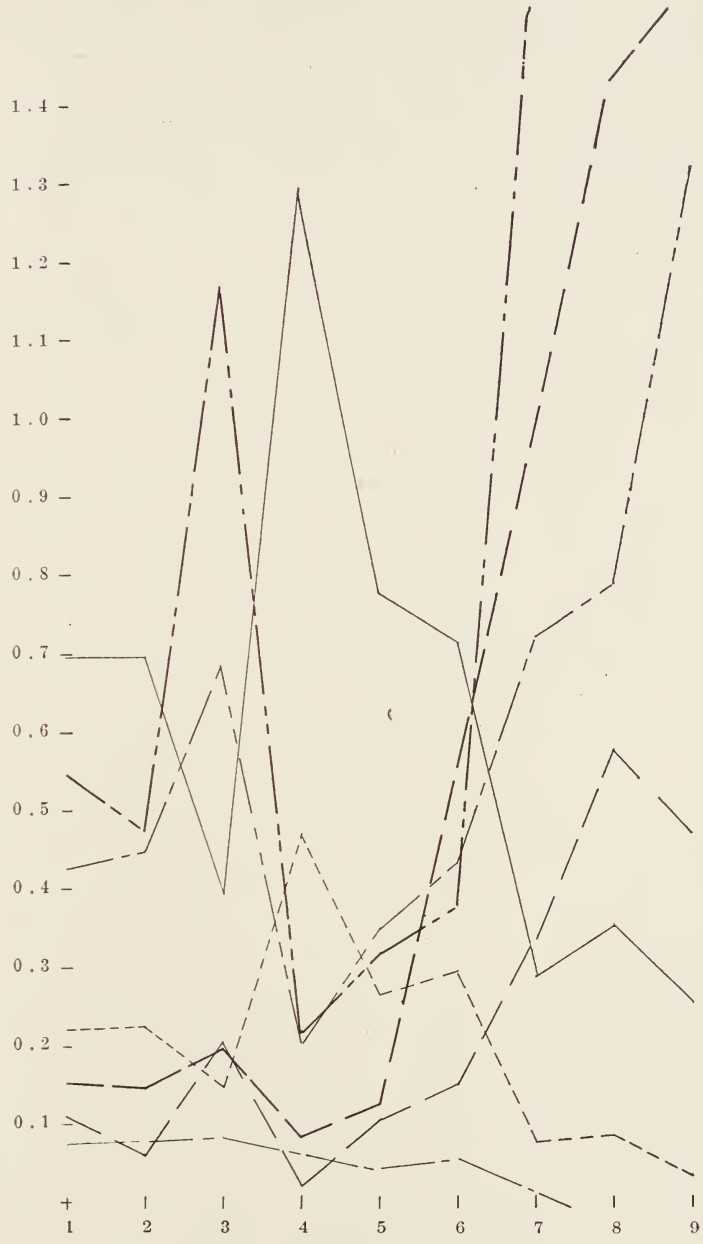

Fig. 19
Copper Sulphate
(See Table 19)

TABLE 20

Copper Sulphate + Zinc Sulphate

No.	Solution $CuSO_4$	Solution $ZuSO_4$	Dry Weight		Mean	Percentage of Ash	Mean	Percentage of Ca	Mean	Percentage of Mg	Mean	Percentage of Ge	Mean	Percentage of Cu	Mean
1	.0000047	.00000382	Tops	.5776		21.60		.151		.490		.088		.....	
				.7157	.6456	24.20	22.90	.085	.128	.462	.476	.123	.105	.....	
			Roots	.5857	.2928	19.80		.149		.299		.065		.002	
2	.0000094	.0000076	Tops	.6286		23.30		.126		.474		.061		.....	
				.4316	.5301	22.20	22.75	.114	.120	.842	.658	.078	.069	.....	
			Roots	.5316	.2658	19.20		.145		.224		.083		.005	
3	.0000142	.0000115	Tops	.6744		22.37		.226		.535		.090		.....	
				.3671	.5207	22.30	22.33	.291	.258	.927	.731	.105	.098	.....	
			Roots	.5022	.2511	16.90		.118		.457		.091		.008	
4	.0000189	.0000153	Tops	.4347		22.30		.322		.666		.105		.....	
				.4325	.4336	23.90	23.10	.312	.317	.607	.636	.102	.103	.....	
			Roots	.2375	.1187	13.37		.477		.426		.116		.011	
5	.0000378	.000036	Tops	.4959		23.30		.532		.747		.055		.....	
				.5333	.5146	24.95	24.10	.593	.561	.698	.717	.066	.060	.....	
			Roots	.2283	.1141	14.30		.513		.661		.018		.052	
6	.0000945	.000076	Tops	.4919		23.10		.794		.790		.090		.....	
				.3918	.4448	26.30	24.70	.598	.696	.755	.722	.080	.080	.....	
			Roots	.2399	.1199	19.50		.990		.636		.025		.025	
7	.0000142	.000153	Tops	.2667		26.90		.790		1.540		.071		.026	
				.3096	.2681	24.20	25.50	.808	.790	1.090	1.31	.055	.063	.019	.022
			Roots	.0924	.0462	20.60		.602		.402		.024		.043	
8	.000189	.000360	Tops	.3574		28.60		.128		.005		.047		.016	
				.3450	35.12	32.24	30.42	.189	.158	1.210	1.10	.032	.040	.017	.016
			Roots	.1038	.0519	24.80		.808		1.910		.011		.058	

Grown March 22–May 3, 1916.

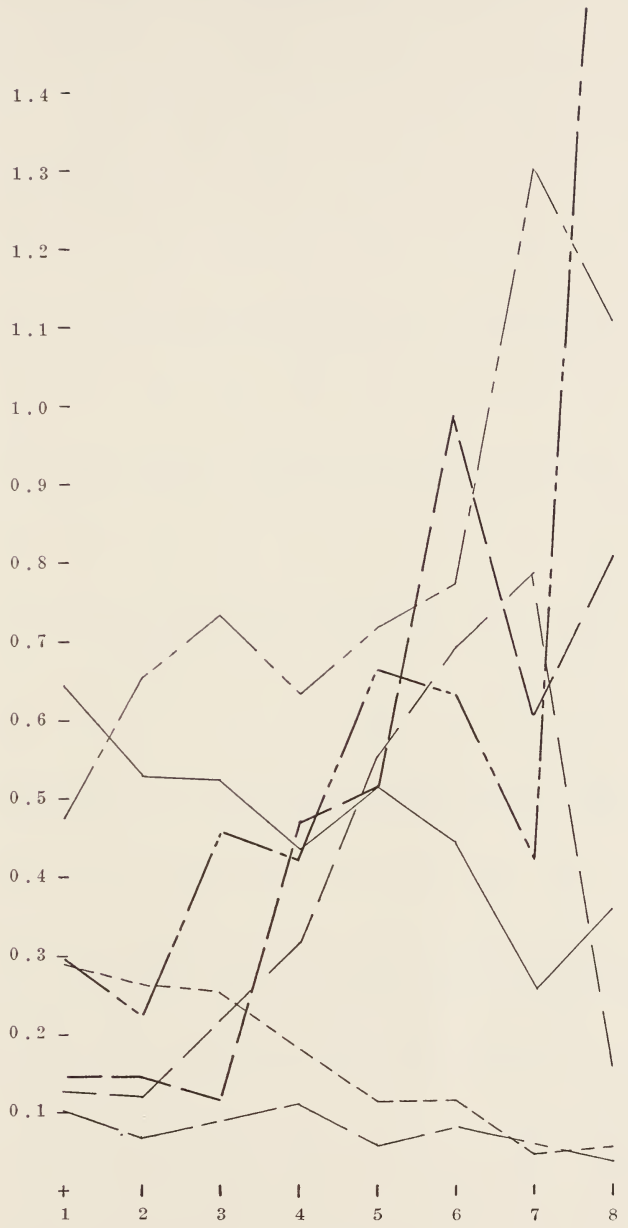

Fig. 20
Copper Sulphate + Zinc Sulphate
(See Table 20)

TABLE 21

Copper Sulphate + Ferric Sulphate

No.	Solution $CuSO_4$	Solution $Fe_2(SO_4)_3$	Dry Weight		Mean	Percentage of Ash	Mean	Percentage of Ca	Mean	Percentage of Mg	Mean	Percentage of Fe	Mean	Percentage of Cu	Mean
1	.0000047	.0000035	Tops	.9739		23.22		.112		.168		.038		.....	
				.9381	.9600	21.40	22.31	.127	.119	.175	.171	.029	.034	.....	
			Roots	.6693	.3346	24.72		.157		.288		.090			
2	.0000094	.0000070	Tops	1.0281		22.50		.171		.171		.054		.....	
				.9758	1.0019	20.60	22.55	.161	.167	.166	.168	.056	.055	.....	
			Roots	.8194	.4097	18.12		.149		.234		.068			
3	.0000142	.0000105	Tops	1.0517		21.05		.117		.168		.057		.....	
				1.2294	1.1405	21.61	21.33	.104	.110	.172	.170	.041	.049	.....	
			Roots	1.0976	.5488	30.38		.103		.202		.042			
4	.0000189	.000014	Tops	.9027		22.14		.125		.156		.056		.....	
				1.0877	.9952	20.00	21.07	.127	.126	.131	.143	.063	.060	.....	
			Roots	.9898	.4949	23.10		.133		.245		.066			
5	.0000378	.000028	Tops	.5927		24.82		.178		.114		.037		.....	
				.9497	.7712	23.10	23.96	.177	.177	.259	.186	.041	.039	.....	
			Roots	.5822	.2991	20.30		.256		.237		.121		.003	
6	.000094	.000070	Tops	.5476		22.10		.194		.330		.033		.....	
				.5050	.5263	22.30	22.20	.212	.203	.....	.330	.041	.037	.....	
			Roots	.1748	.0874	24.41		.520		.118		.190			
7	.000142	.000105	Tops	.4324		22.10		.206		.402		.025		.001	
				.4742	.4533	20.91	21.50	.198	.202	.442	.422	.025	.025	.002	.002
			Roots	.1796	.0898	21.65		.617		.289		.117		.001	
8	.000189	.00014	Tops	.4612		22.21		.267		.602		.191		.001	
				.3774	.4193	21.62	21.91	.366	.316	.675	.638	.172	.181	.002	.002
			Roots	.0744	.0387	16.40		.177		.257		.042		.002	
9	.00058	.00028	Tops	.2887		22.52		.123		1.010		.191		.007	
				.2957	.2922	23.90	23.21	.114	.118	1.240	1.12	.113	.151	.005	.063
			Roots	.0707	.0353	19.81		.129		2.290		.627		.....	
10	.0000094	.000007	Tops	1.1573		19.96		.259		.251		.337		.....	
				.8900	1.0236	18.13	19.04	.223	.241	.187	.219	.375	.356	.....	
		$ZnSO_4$ .0000076	Roots	.7939		20.40		.100		.186		.091		.004	

Grown March 22–May 3, 1916.

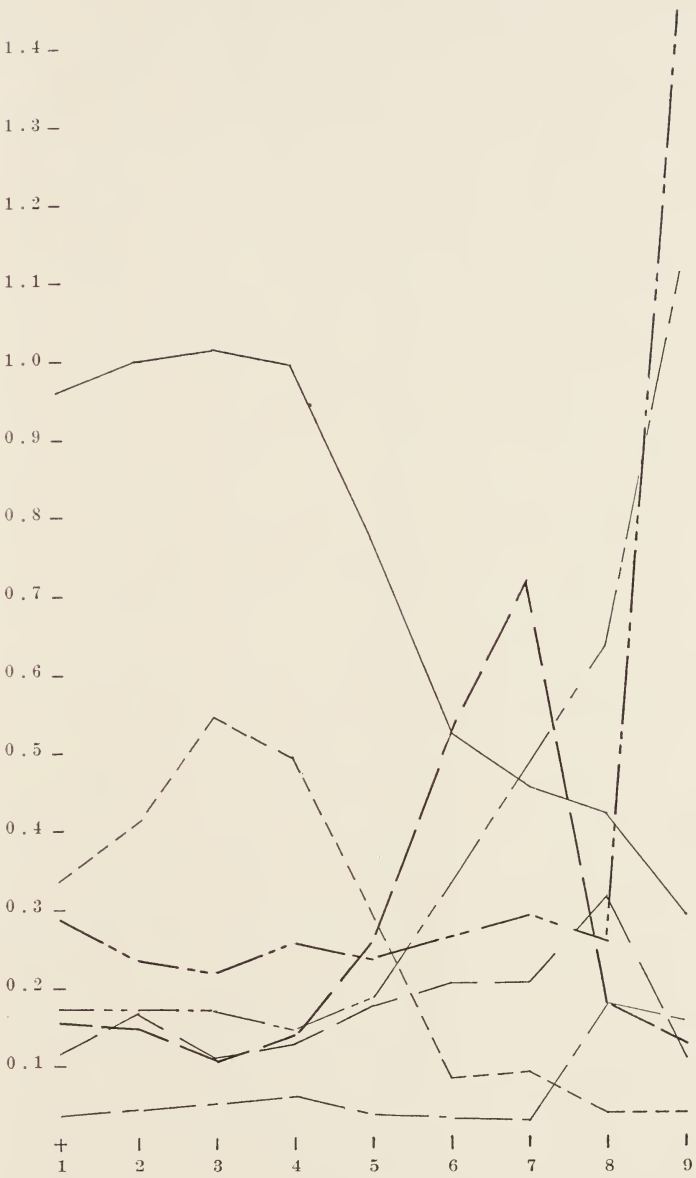

Fig. 21
Copper Sulphate + Ferric Sulphate
(See Table 21)

TABLE 22

Ferric Sulphate

No.	Solution $Fe_2(SO_4)_3$	Dry Weight		Mean	Percentage of Ash	Mean	Percentage of Ca	Mean	Percentage of Mg	Mean	Percentage of Fe	Mean
1	.0000014	Tops	2.2399		17.09		.107		.098		.246	
			1.3062	1.7730	17.55	17.32	.099	.103	.113	.105	.281	.263
		Roots	1.0626		21.81		.122		.763		.315	
			.....	.5313	.....	21.81	.....	.122	.....	.763	.....	.315
2	.0000028	Tops	1.9198		20.50		.119		.070		.264	
			1.5226	1.7210	20.21	21.35	.115	.117	.072	.071	.201	.231
		Roots	.8731		25.50		.013		.145		.220	
			.4850	.6769	26.50	25.85	.020	.016	.158	.150	.286	.253
3	.0000070	Tops	1.4150		24.00		.095		.....		.393	
			1.5247	1.4698	22.62	23.31	.080	.087	.102	.102	.395	.394
		Roots	.6984		31.10		.032		.263		.223	
			.7624	.7304	30.61	30.85	.041	.036	.224	.243	.277	.250
4	.000014	Tops	2.3544		20.57		.032		.089		.358	
			2.3461	2.3502	18.90	19.73	.041	.036	.106	.097	.378	.368
		Roots	1.0361		27.20		.022		.184		.172	
			1.1861	1.1111	29.20	28.31	.011	.016	.250	.217	.178	.175
5	.00007	Tops	4.2000		14.80		.018		.072		.236	
			3.6033	3.9016	15.15	14.97	.017	.017	.073	.072	.268	.252
		Roots	.9813		25.81		.056		.134		.103	
			.9168	.9490	26.00	25.90	.077	.067	.118	.128	.129	.116
Full Nutrient		Tops	1.5682		18.33		.293		.231			
			1.5775	1.5728	19.40	18.86	.312	.302	.279	.255		
		Roots	.9776		20.40		.271		.279			

Grown April 22–June 3, 1916.

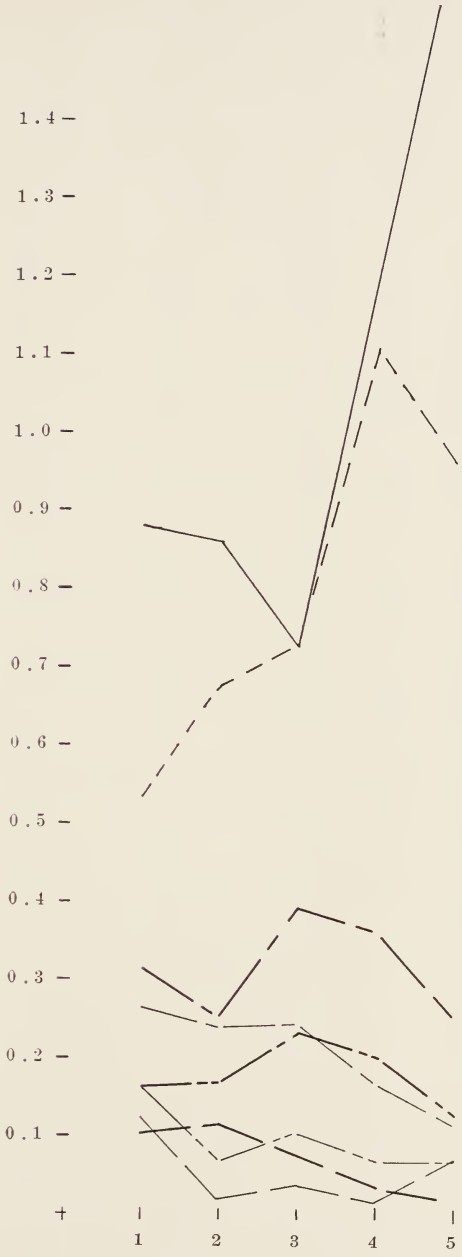

Fig. 22
Ferric Sulphate
(See Table 22)

TABLE 23

Zinc Sulphate

No.	Solution $ZnSO_4$	Dry Weight		Mean	Percentage of Ash	Mean	Percentage of Ca	Mean	Percentage of Mg	Mean	Percentage of Fe	Mean
1	.00000767	Tops	.6718		23.00		.324		.374		.0622	
			.7541	.7129	24.04	23.52	.341	.332	.560	.467	.0587	
		Roots	.6138	.3069	17.88		.191		.....		.....	
2	.0000131	Tops	.7164		25.30		.326		.310		.121	
			.8350	.7757	24.65	25.07	.284	.305	.386	.348	.101	
		Roots	.6009	.3004	17.20		.187		.358		.101	
3	.0000395	Tops	.6142		21.19		.372		.324		.0708	
			.8607	.7374	22.50	21.84	.316	.344	.320	.322	.0644	
		Roots	.5864	.2932	15.90		.166		.886			
4	.000153	Tops	.5109		21.90		.372		.660		.097	
			.3800	.4454	19.40	20.65	.437	.404	.760	.710	.981	.089
		Roots	.4628	.2314	20.50		.128		.423		.074	
5	.000395	Tops	.8208		20.38		.200		.321		.073	
			Lost	.4104	.....	20.38	.....	.200	.....	.321	.....	.073
		Roots	.4432	.2216	22.30		.053		.810		.017	
Full Nutrient		Tops	1.0992		20.17		.310		.268			
			1.0750	1.0872	19.12	18.69	.297	.303	.228	.224		
		Roots	.8120		20.00		.271		.233			

Grown January 24–March 6, 1916.

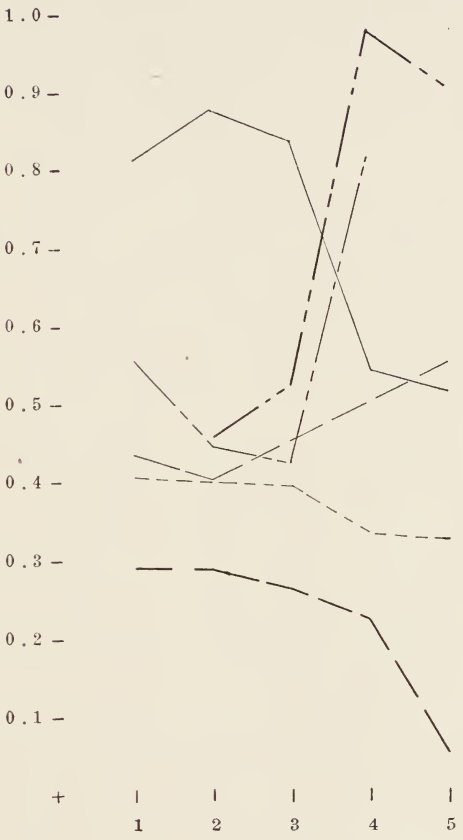

Fig. 23
Zinc Sulphate
(See Table 23)

TABLE 24

Zinc Sulphate + Ferric Sulphate

No.	Solution $ZnSO_4$	Solution $Fe_2(SO_4)_3$		Dry Weight	Mean	Percentage of Ash	Mean	Percentage of Ca	Mean	Percentage of Mg	Mean	Percentage of Fe	Mean
1	.0000019	.0000035	Tops	1.0594		18.50		.096		.215		.031	
				1.5294	1.2944	18.70	18.60	.098	.097	.230	.222	.029	.030
			Roots	.10444	.5222	29.80		.045		.149		.037	
2	.0000038	.000005	Tops	1.5364		18.60		.149		.262		.036	
				1.4864	1.5114	16.10	17.35	.170	.159	.231	.247	.030	.033
			Roots	1.0716	.5258	31.00		.042		.184		.082	
3	.0000057	.000007	Tops	1.2300		18.10		.172		.288		.076	
				1.6150	1.4225	16.90	17.00	.124	.140	.277	.282	.064	.070
			Roots	1.1250	.5625	32.30		.068		.130		.010	
4	.0000076	.000014	Tops	2.3088		16.40		.083		.110		.065	
				2.5100	2.4094	17.00	16.70	.098	.090	.111	.110	.062	.063
			Roots	1.5623	.7812	28.00		.040		.139		.061	
5	.0000152	.000028	Tops	2.3429		15.70		.154		.151		.052	
				2.0129	2.1774	15.70	15.70	.147	.150	.158	.154	.046	.049
			Roots	1.5133	.7566	30.30		.050		.103		.069	
6	.0000379	.000070	Tops	2.0533		18.10		.160		.122		.042	
				1.5544	1.8038	16.20	17.15	.160	.160	.151	.136	.049	.045
			Roots	1.4194	.7097	25.30		.025		.243		.141	
7	.000076	.00014	Tops	1.6164		18.40		.157		.....		.0412	
				1.7228	1.6696	19.70	19.05	.144	.150	.201		.0412	.043
			Roots	1.7611	.8801	27.00		.019		.317		.128	
8	.000152	.00028	Tops	.9850		18.35		.179		.219		.045	
				1.0268	1.0029	20.00	19.17	.176	.177	.282	.250	.042	.043
			Roots	.6987	.3493	27.30		.006		.367		.....	

Grown April 24–June 6, 1916.

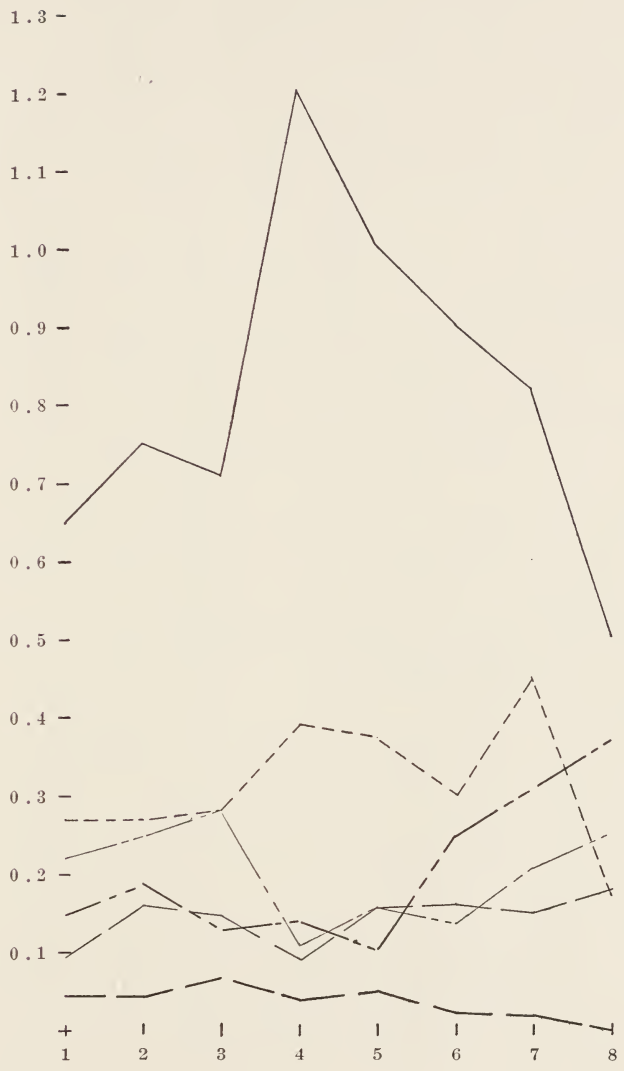

Fig. 24
Zinc Sulphate + Ferric Sulphate
(See Table 24)

TABLE 25

Mercuric Chloride + Ferric Sulphate

No.	Solution $HgCl_2$	Solution $Fe_2(SO_4)_3$	Dry Weight		Mean	Percentage of Ash	Mean	Percentage of Ca	Mean	Percentage of Mg	Mean	Percentage of Fe	Mean
1	.0000047	.0000035	Tops	.2039		22.40		.233		.723			
				.2868	.2553	16.70	19.55	.179	.206	.513	.618		
			Roots	.0518	.0259	18.70		.840		2.670			
2	.0000094	.0000070	Tops	.2569		21.75		.123		.327			
				.3579	.3074	21.90	21.82	.138	.230	.515	.421		
			Roots	.0869	.0434	18.90		.222		2.95			
3	.0000189	.00005	Tops	.2042		16.70		.172		.371			
				.2996	.2519	19.40	18.05	.231	.201	.412	.391		
			Roots	.0896	.0448	18.13		.271		.312			
4	.000047	.00014	Tops	.2362		17.32		.192		.416			
				.2300	.2331	17.41	17.36	.183	.187	.511	.463		
			Roots	.0596	.0298	19.01		.221		2.110			
5	.000094	.0007	Tops	.2396		16.10		.420		.100			
				Lost	.2396	.....	16.10	.....	.420	.....	.100		
			Roots	.0237	.0118	15.50		.151		4.580			
6	.000189	.00105	Tops	.2288		16.70		.201		.731			
				.2988	.2638	17.20	16.95	.131	.166	.807	.769		
			Roots	.0784	.0392	21.30				2.170			
7	.000378	.00210	Tops	.2184		15.61		.190		.895		.101	
				.4272	.3228	17.40	16.50	.102	.146	.550	.722	.157	.129
			Roots	.0496	.0248	18.10		.232		.738		.222	

Not enough present to determine.

Grown March 22–May 3, 1916.

Fig. 25
Mercuric Chloride + Ferric Sulphate
(See Table 25)

TABLE 26

Mercuric Chloride

No.	Solution $HgCl_2$	Dry Weight		Mean	Percentage of Ash	Mean	Percentage of Ca	Mean	Percentage of Mg	Mean	Percentage of Fe	Mean
1	.0000135	Tops	.4904		17.20		.141		.91		.248	
			.4967	.4935	16.71	16.95	.098	.120	.....	.91	.....	.248
		Roots	.1493	.0746	19.31		.478		.893		.296	
2	.000066	Tops	.2200		15.70		.332		1.69		.010	
			.2236	.2218	14.24	14.97	.380	.356	1.77	1.73	.017	.013
		Roots	.0239	.0119	10.50		4.31		.775		.013	
3	.000135	Tops	.1514		9.12		.421		1.23		.012	
			.1421	.1467	8.95	9.03	.399	.410	1.33	1.28	.013	.012
		Roots	.....									

Grown March 14–April 24, 1916.

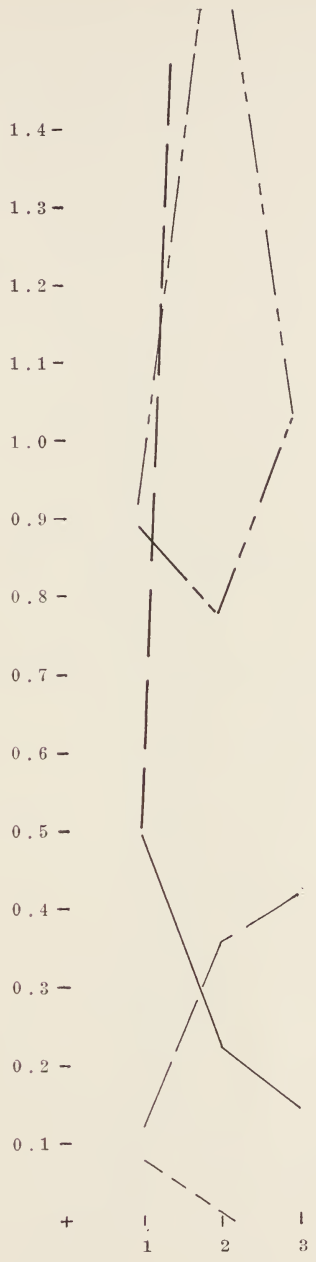

Fig. 26
Mercuric Chloride
(See Table 26)

EXPLANATION OF PLATES

PLATE 13

Appearance of plants as mounted in corks at expiration of the six weeks' growing period.

PLATE 14

No. 1. .24 M. $MgCl_2$ .004 M. $CaCl_2$
No. 2. .24 M. $MgCl_2$ .01 M. $CaCl_2$
No. 3. .24 M. $MgCl_2$ .02 M. $CaCl_2$
No. 4. .24 M. $MgCl_2$ .04 M. $CaCl_2$
No. 5. .24 M. $MgCl_2$ .06 M. $CaCl_2$
No. 6. .24 M. $MgCl_2$ .08 M. $CaCl_2$
No. 7. .24 M. $MgCl_2$ .10 M. $CaCl_2$
No. 8. .24 M. $MgCl_2$ .12 M. $CaCl_2$
No. 9. .24 M. $MgCl_2$ .16 M. $CaCl_2$
No. 10. .24 M. $MgCl_2$ .20 M. $CaCl_2$
No. 11. .24 M. $MgCl_2$ .24 M. $CaCl_2$
No. 12. .24 M. $MgCl_2$ .30 M. $CaCl_2$
No. 13. .24 M.
Control.

PLATE 15

No. 1. .30 M. $MgCl_2$ .004 M. $CaCl_2$
No. 2. .30 M. $MgCl_2$ .01 M. $CaCl_2$
No. 3. .30 M. $MgCl_2$ .02 M. $CaCl_2$
No. 4. .30 M. $MgCl_2$ .04 M. $CaCl_2$
No. 5. .30 M. $MgCl_2$ .06 M. $CaCl_2$
No. 6. .30 M. $MgCl_2$ .08 M. $CaCl_2$
No. 7. .30 M. $MgCl_2$ .10 M. $CaCl_2$
No. 8. .30 M. $MgCl_2$ .12 M. $CaCl_2$
No. 9. .30 M. $MgCl_2$ .16 M. $CaCl_2$
No. 10. .30 M. $MgCl_2$ .20 M. $CaCl_2$
No. 11. .30 M. $MgCl_2$ .24 M. $CaCl_2$
No. 12. .30 M. $MgCl_2$ .30 M. $CaCl_2$
Control.

PLATE 16

No. 1. .04 M. KCl
No. 2. .06 M. KCl
No. 3. .08 M. KCl
No. 4. .10 M. KCl
No. 5. .12 M. KCl
No. 6. .14 M. KCl
No. 7. .16 M. KCl

PLATE 17

No. 1. .00331 M. $AlCl_3$
No. 2. .000331 M. $AlCl_3$
No. 3. .000132 M. $AlCl_3$
No. 4. .000066 M. $AlCl_3$
No. 5. .000033 M. $AlCl_3$
No. 6. .0000165 M. $AlCl_3$
No. 7. .0000033 M. $AlCl_3$
Control.

PLATE 18

No. 1. .0168 M. $FeCl_3$ .20 M. $MgCl_2$
No. 2. .0058 M. $FeCl_3$ .20 M. $MgCl_2$
No. 3. .00356 M. $FeCl_3$ .20 M. $MgCl_2$
No. 4. .00142 M. $FeCl_3$ .20 M. $MgCl_2$
No. 5. .000712 M. $FeCl_3$ .20 M. $MgCl_2$
No. 6. .000352 M. $FeCl_3$ .20 M. $MgCl_2$
No. 7. .000168 M. $FeCl_3$ .20 M. $MgCl_2$
No. 8. .000089 M. $FeCl_3$ .20 M. $MgCl_2$
Control.

PLATE 19

No. 1. .00331 M. $AlCl_3$ .20 M. $CaCl_2$
No. 2. .000331 M. $AlCl_3$ .20 M. $CaCl_2$
No. 3. .000132 M. $AlCl_3$ .20 M. $CaCl_2$
No. 4. .0000662 M. $AlCl_3$ .20 M. $CaCl_2$
No. 5. .0000331 M. $AlCl_3$ .20 M. $CaCl_2$
No. 6. .0000165 M. $AlCl_3$ .20 M. $CaCl_2$
No. 7. .0000033 M. $AlCl_3$ .20 M. $CaCl_2$
Control.

PLATE 20

No. 1.	.000094	M. $CuCl_2$	.00082	M. $FeCl_3$
No. 2.	.000067	M. $CuCl_2$	.000058	M. $FeCl_3$
No. 3.	.000047	M. $CuCl_2$	.000042	M. $FeCl_3$
No. 4.	.000028	M. $CuCl_2$	.000026	M. $FeCl_3$
No. 5.	.0000094	M. $CuCl_2$	.0000089	M. $FeCl_3$

Control.

PLATE 21

No. 1. .000378 M. $CuSO_4$
No. 2. .000189 M. $CuSO_4$
No. 3. .0000945 M. $CuSO_4$
No. 4. .0000755 M. $CuSO_4$
No. 5. .0000567 M. $CuSO_4$
No. 6. .0000378 M. $CuSO_4$
No. 7. .0000188 M. $CuSO_4$
No. 8. .0000094 M. $CuSO_4$
No. 9. .0000048 M. $CuSO_4$
Control.

PLATE 22

No. 1.	.0000047	M. $CuSo_4$	.0000035	M. $Fe_2 (SO_4)_3$
No. 2.	.0000094	M. $CuSo_4$	.0000070	M. $Fe_2 (SO_4)_3$
No. 3.	.0000142	M. $CuSo_4$	.0000105	M. $Fe_2 (SO_4)_3$
No. 4.	.0000189	M. $CuSo_4$	.000014	M. $Fe_2 (SO_4)_3$
No. 5.	.0000378	M. $CuSo_4$	.000028	M. $Fe_2 (SO_4)_3$
No. 6.	.000094	M. $CuSo_4$	.000070	M. $Fe_2 (SO_4)_3$
No. 7.	.000142	M. $CuSo_4$	.000105	M. $Fe_2 (SO_4)_3$
No. 8.	.000189	M. $CuSo_4$	.00014	M. $Fe_2 (SO_4)_3$
No. 9.	.00058	M. $CuSo_4$	.00028	M. $Fe_2 (SO_4)_3$

Control.

PLATE 23

No. 1. .0000014 M. $Fe_2(SO_4)_3$
No. 2. .0000028 M. $Fe_2(SO_4)_3$
No. 3. .0000070 M. $Fe_2(SO_4)_3$
No. 4. .000014 M. $Fe_2(SO_4)_3$
No. 5. .00007 M. $Fe_2(SO_4)_3$
Control.

PLATE 24

No. 1. .000135 M. $HgCl_2$
No. 2. .000066 M. $HgCl_2$
No. 3. .0000135 M. $HgCl_2$
Control.